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ANALYSIS OF WIND TUNNEL DATA FOR SEVERAL BECKMAN & WHITLEY SERIES 50 AND CLIMET MODEL C1-14 ANEMOMETERS

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George C. Marshall Space Flight Center, Huntsville, Alabama

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ABSTRACT

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This report presents results of wind tunnel test data for several Beckman & Whitley Series 50 and Climet Model C1-14 anemometers. The primary purpose of the wind tunnel testing was the determination of the following two response parameters: the distance constant and the damping ratio of the anemometers.

The dependence of the distance constant on the electronic filter used to filter the output signal of the wind speed sensor is discussed. The importance of the distance constant in measuring the fluctuations of the wind is illustrated by showing how this parameter affects the frequency response curves of the anemometers. The average values of the distance constants were found to be 1.14 meters for the Beckman & Whitley Series 50 and 0.73 meters for the Climet Model C1-14.

The damping ratio, in agreement with theory, is shown to be independent of wind speed. The values obtained for this parameter were 0.59 for the Beckman & Whitley Series 50 and 0.47 for the Climet Model C1-14 anemometers.

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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AERO-ASTRODYNAMICS LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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ANALYSIS OF WIND TUNNEL DATA FOR SEVERAL BECKMAN & WHITLEY SERIES 50 AND CLIMET MODEL C1-14 ANEMOMETERS

SUMMARY

This report presents results of wind tunnel test data for several Beckman & Whitley Series 50 and Climet Model C1-14 anemometers. The primary purpose of the wind tunnel testing was the determination of the two following response parameters: the distance constant and the damping ratio of the anemometers. The average values of the distance constants obtained from the testing were 1.14 and 0.73 meters for the Beckman & Whitley and Climet anemometers, respectively. For the damping ratio, the average values were found to be 0.59 for the Beckman & Whitley anemometers and 0.47 for the Climet anemometers.

A discussion is presented on the dependence of the distance constant on the electronic filter used to filter the output signal of the wind speed sensor.

INTRODUCTION

When measurements of the wind are made, the accuracy of the measuring instrument should be understood as thoroughly as possible. To properly interpret wind data as measured by an anemometer, it is necessary to know the response characteristics of the anemometer. The distance constant and the damping ratio are the two parameters which are generally used to determine the response characteristics of an anemometer. Knowledge of the above parameters becomes more important in measuring high frequencies which approach the capability of the instrument. The amplitude resolution as a function of frequency is determined by the distance constant.

The damping ratio is used to determine how well a wind vane will indicate the true wind direction, that is, how the vane will follow the wind when there is a change in direction. In various space vehicle studies, such as the on-pad response of the vehicle to winds, the accurate measurement of wind speed as a function of frequency, and wind direction as a function of the change may be very important. The frequency response characteristics of anemometers is usually not critical for measuring average wind speeds and directions over several minutes and longer, but must be accurately known if high frequency measurements are to be made. Most commercially available anemometers do not have the capability for measuring winds at a frequency above 1 - 2 cyc/sec. The response characteristics given by the distance constant and damping ratio may be determined in a wind tunnel. This was done for a number of Beckman & Whitley Series 50 and Climet C1-14 anemometers in the White Sands Missile Range wind tunnel to obtain a better understanding of the instruments and to establish their capabilities for measuring the higher frequencies. These anemometers are to be usedon the 500-foot meteorological tower and various launch complexes at Cape Kennedy.

The participation and assistance received from the various people who made these tests and this report possible are greatly appreciated. Those making notable contributions were Messrs. Roy I. Glass, Roy E. Price, Bert Saldana, Joseph Weber, and SP-5 Allen Petterson of the Environmental Sciences Department, U. S. Army R&D Activity, White Sands Missile Range, New Mexico; and Mr. George Norwood of the Atmospheric Measuring Group, and Mr. Wade Perry of the Environmental Applications Group, NASA, Huntsville, Alabama.

WIND TUNNEL FACILITY

The wind tunnel used was the Wind Instrumentation Research Facility located at the White Sands Missile Range (WSMR), New Mexico. This wind tunnel is a low speed closed circuit system having features which make it ideally suited for calibrating and investigating anemometers. The test chamber is a rectangular parallelepiped having dimensions of 4x4x6 feet. The six-foot side is parallel to the wind flow. Foam rubber gaskets approximately 1.5 inches thick are used to isolate the test chamber from the main structure. These gaskets reduce the vibration transfer between the test chamber and the main structure. The contraction section of the tunnel follows an exponential function and has a ratio of approximately five to one.

Air movement (wind) in the tunnel is generated by a blower, which has both speed and pitch controls. The approximate wind speed range for the tunnel is 0.22 to 38.0 meters per second. Speed control in increments of 0.04 meters per second is possible for low wind speeds. The instrumentation used to measure tunnel wind speed consists of a Prandtl tube, an eddy-shed hot wire sensor, and a mean-velocity hot wire sensor.

Further information on the above and other factors concerning the wind tunnel facility are given in Reference 1.

RESPONSE PARAMETERS INVESTIGATED

The response characteristics of the wind speed and direction sensors were investigated by checking the consistency of experimentally determined distance constants and damping ratios of the respective sensors. A better interpretation of the variations in the wind data can be made if the parameters are consistent from measurement to measurement. The distance constant, L, is defined as the length of a column of air after a sharp-edge gust, or partial lull, has occurred for the anemometer speed to reach 63 percent of the new equilibrium value (Ref. 2). The distance constant is given by

$$L = \bar{u}\tau, \tag{1}$$

where $\bar{u}$ is the equilibrium speed and τ is the time constant. The time constant varies inversely with the equilibrium wind speed. In determining the time constants from the WSMR tests, no attempt was made to determine the zero time point on the chart records. Rather, a convenient point on the chart was chosen where the initial oscillations had damped out. The point used for the zero time point will be discussed further in the next section of this report.

The parameter used to check the response of the vanes was the damping ratio. This ratio, h, is given by (Refs. 3 and 4)

$$h = \left[1 + \left(\frac{\pi}{\ln(x_1/x_2)}\right)^2\right]^{-\frac{1}{2}} \tag{2}$$

where x_1 is the number of degrees the vane is deflected relative to the direction of the tunnel flow and x_2 is the number of degrees the vane overshoots the equilibrium value when suddenly released. This equation is for vanes which have a very small second excursion.

The Honeywell 1612 Visicorder oscillograph as shown in Figure 1 was used to record the wind tunnel data. Figures 2 and 3 show the Beckman & Whitley Series 50 and Climet Model C1-14, respectively.

ANALYSIS OF THE WIND TUNNEL DATA

In all the wind tunnel tests three wind speeds were used: 4.47, 8.94, and 13.41 meters per second. Deflection angles used in the vane response portion were 10 and 20 degrees.

For the Beckman & Whitley Series 50 "Staggered-Six" cup assembly, the cups were orientated with one of the top three cups convex to the tunnel flow (Fig. 4). However, because of the way the cups are assembled, there would be no difference in the test results had a different cup orientation been used. The cup orientation for the Climet system was for one of the cup arms to be pointing into the wind flow (Fig. 5). This orientation was chosen to obtain a value of the distance constant that would be representative of both locked-rotor and braking values as described by Schubauer and Adams (Ref. 2).

In addition to testing the response characteristics of the anemometers, a high wind speed test was run on one Beckman & Whitley Series 50 wind speed sensor and one Climet Model 011-1 wind speed sensor. Each test was started at a tunnel wind speed of 4.47 meters per second and steadily increased to the maximum tunnel speed. For these two tests the maximum tunnel speed was approximately 38.0 meters per second. The tunnel wind speed was determined by use of an Aerovane anemometer mounted down tunnel from the anemometer being tested. Both anemometers met the objectives of the tests, that is, to operate and to measure the wind speed at the highest tunnel wind speed possible.

In the wind speed response portion of the WSMR tests, the initial conditions were cups locked (unable to rotate) in the position as previously described, and then the tunnel wind speed was brought to a predetermined equilibrium value. When the wind speed had reached the equilibrium value, the cups were unlocked. The wind speed as measured by use of the cups was recorded before (0 m/sec), during, and after the equilibrium wind speed had been reached (Figures 6 through 11). From these records, it is possible to determine the time constant of the anemometer if the chart speed of the recorder is known. To determine the time constants from the wind tunnel records the initial time (zero time) was considered to be at the point where the wind speed trace crossed the 2.235, 4.470, and 6.705 meters per second lines for the three speeds used: 4.47, 8.94, and 13.41, respectively. This was done to obtain a better estimate of the distance constants. In all tests for determining the distance constant and the damping ratio, the chart speed was 0.102

meters per second. Once the time constant is found, the distance constant can be computed by use of equation (1) if the equilibrium speed is known. As previously stated the equilibrium speeds were 4.47, 8.94, and 13.41 meters per second, and were known for each test. The mean values of the distance constants for the WSMR wind tunnel tests are given in Table I. In this table the distance constants are given according to wind speed and make of anemometer. The number of observations used to determine each of the mean distance constant values is given immediately after the distance constant.

The distance constant for the Beckman & Whitley Series 50 decreases for an increasing wind speed by approximately 10 percent. The Climet Model C1-14 increased by approximately 6 percent for an increasing wind speed.

For both the Beckman & Whitley Series 50 and the Climet Model C1-14 anemometers, the value obtained for the distance constant is in good agreement with company specifications (Ref. 4 and 5). The distance constants for both anemometers, however, were found to be directly dependent on the electronic filter used in filtering the output signal of the wind speed sensors. The filters used on the respective anemometers were optimized for a wind speed of 13.41 meters per second. A schematic of the filters used is shown in Figures 12 and 13. These filters were developed experimentally at WSMR before the tests to provide an acceptable noise level for the range of speeds used.

The effect of the electronic filter on the output signal can be seen by a comparison of Figures 6 and 7. The same filter was used to obtain the wind speed traces for both figures. Figure 6 has a greater amount of oscillation (ripple) in its trace than Figure 7. The amplitude of this ripple is obviously a function of wind speed. The major portion of this ripple results from d.c. pulses, output signal of the wind speed sensor, which have been passed by the filter used (Fig. 12). If the signal of Figure 6 had been filtered to the extent that its trace was as smooth as that of Figure 7, then the distance constant would have been greatly increased. This is a consequence of the fact that the signal passed by the filter is a function of frequency; the higher the frequency the smoother the output. Further filtering would also have smoothed the trace of Figure 7 more. Another effect of more filtering (smoother output) is that the range of wind speed for which the distance constant is approximately constant is altered. Thus, the characteristics of the electronic filter may be as important or maybe even more important, than the response characteristics of the sensor.

The importance of the distance constants is illustrated by the response curves given in Figures 14 and 15 for the Beckman & Whitley Series 50 and the Climet Model C1-14, respectively. A comparison of the figures shows that the Climet anemometer measures the amplitude of the wind speed fluctuations more precisely to a higher gust frequency than the Beckman & Whitley Series 50. For example, at a frequency of 5.0 cycles per second and a wind speed of 13.41 meters per second, the Climet anemometer measures approximately 50.0 percent of the amplitude as compared to 35.0 percent for the Beckman & Whitley Series 50. These theoretical results were obtained under controlled conditions.

The damping ratio of a wind vane is a parameter which gives an indication of how the vane resists overshooting the wind direction when there has been a change in wind direction (Ref. 3). For a discussion on the damping ratio, reference should be made to any good analytical mechanics book, e.g., Reference 6.

Equation (2) shows that the damping ratio is independent of wind speed. However, three wind speed values were used in determining the ratio (4.47, 8.94, and 13.41 meters per second). To determine the damping ratio, the wind vane was deflected through a known angle (10 or 20 degrees) with respect to the tunnel flow for a given wind speed and then released. A record was made of the actions of the vane during the deflected portion, during the approach back to the tunnel flow direction and for a short time after the vane had stabilized (Figures 16 through 27).

The damping ratios were determined by equation (2). The ratio values are given in terms of speed and deflection angle in Table II, which also gives the number of observations used in determining the damping ratio.

The values of the damping ratio for the Beckman & Whitley Series 50 Quick 1 Vane given in the table are in excellent agreement with the value quoted in company specifications (Ref. 4). Also a comparison shows that the values obtained from the tests and listed in the table for the Climet Model 012-1 Vane are higher than those given by company specifications (Ref. 7). This indicates that the Climet vanes tested were slightly better than specified by the manufacturer. The average values of the damping ratios were 0.59 for the Beckman & Whitley Quick 1 Vane and 0.47 for the Climet Model 012-1 Vane.

COMMENTS AND CONCLUSIONS

This analysis of wind tunnel data for several Beckman & Whitley Series 50 and Climet Model Cl-14 anemometer systems was primarily concerned with the damping ratio and the distance constant. The damping ratios and the distance constants of the anemometers tested were found to be essentially in agreement with company specifications (Refs. 4, 5, and 7). It has been shown that although fairly good wind data can be obtained to gust frequency of 3 - 5 cycles per second with either of the two types of anemometers tested, the Climet Cl-14 has the better response. Because the data obtained from either of the wind speed sensors is greatly influenced by the electronic filter, care should be exercised in selecting one for use in obtaining wind data from these types of anemometers. The response parameters given in this report were theoretically obtained under controlled conditions (wind tunnel), and may not be indicative of the responses to true atmospheric conditions.

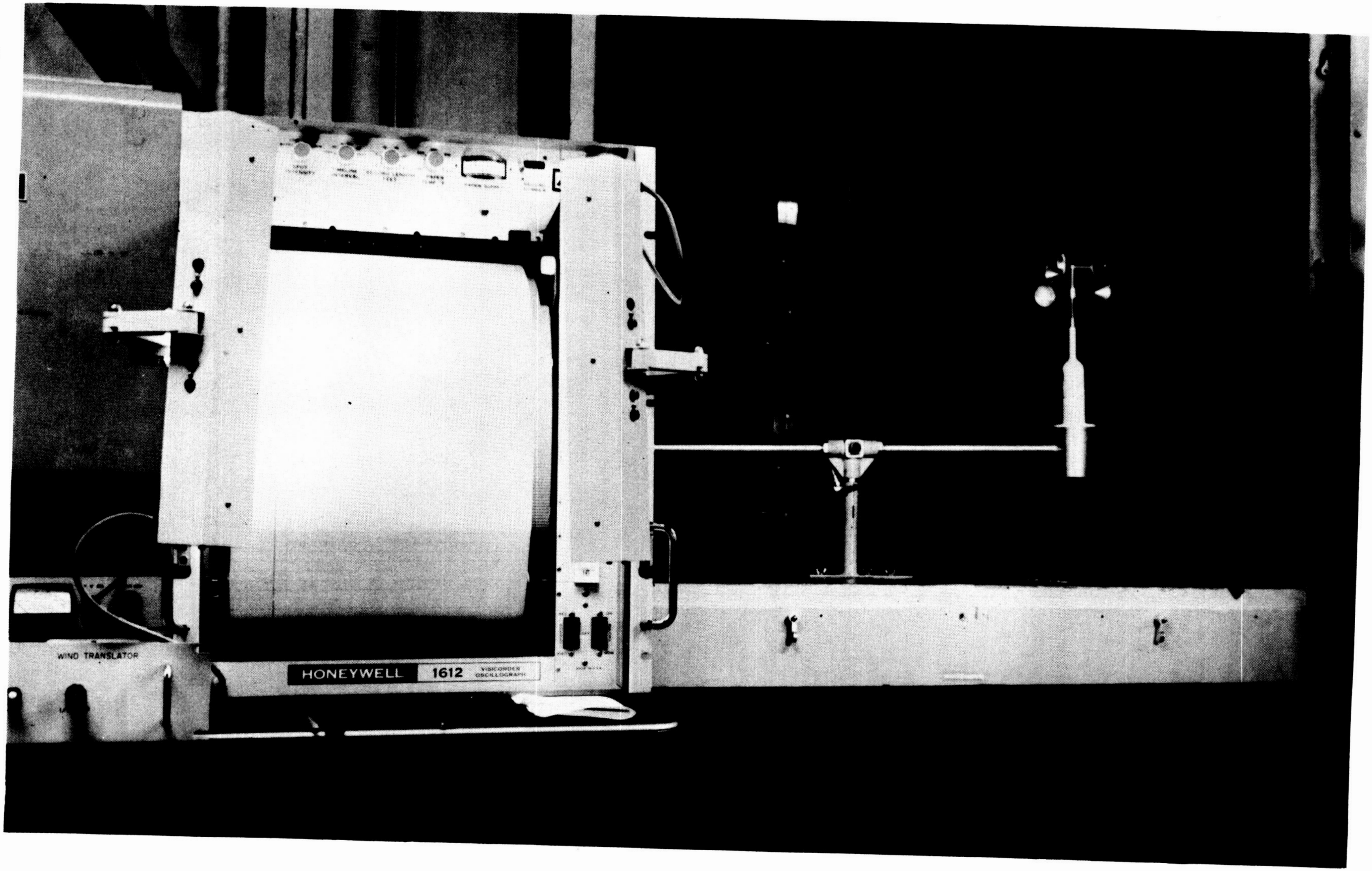


Figure 1. Visicorder Oscillograph and Beckman & Whitley Series 50 Anemometer at the Wind Tunnel Facility, White Sands Missile Range, New Mexico (Photo courtesy of U.S. Army, WSMR)

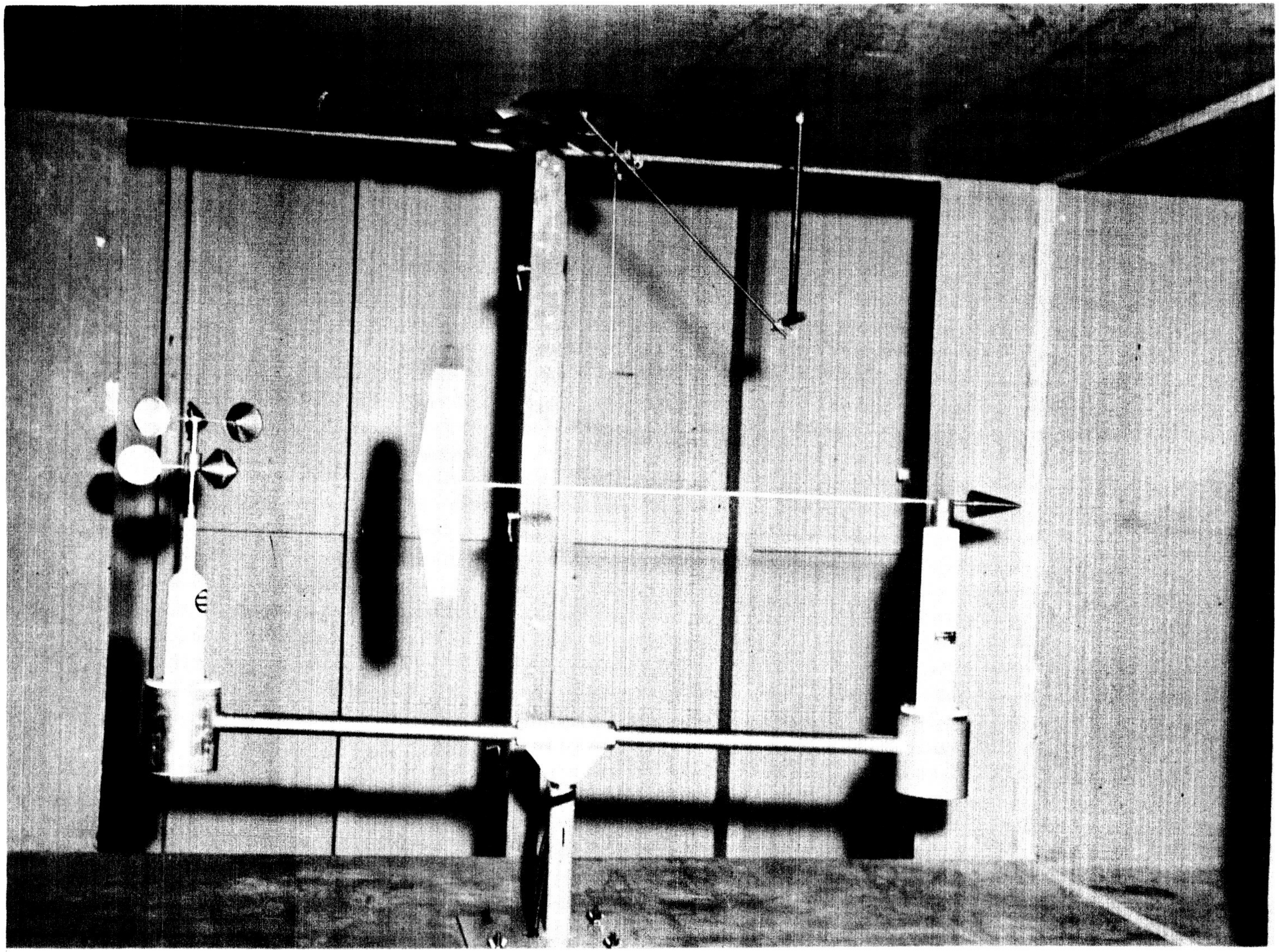


Figure 2. Beckman & Whitley Series 50 Anemometers Inside Wind Tunnel (Photo courtesy of U.S. Army WSMR)

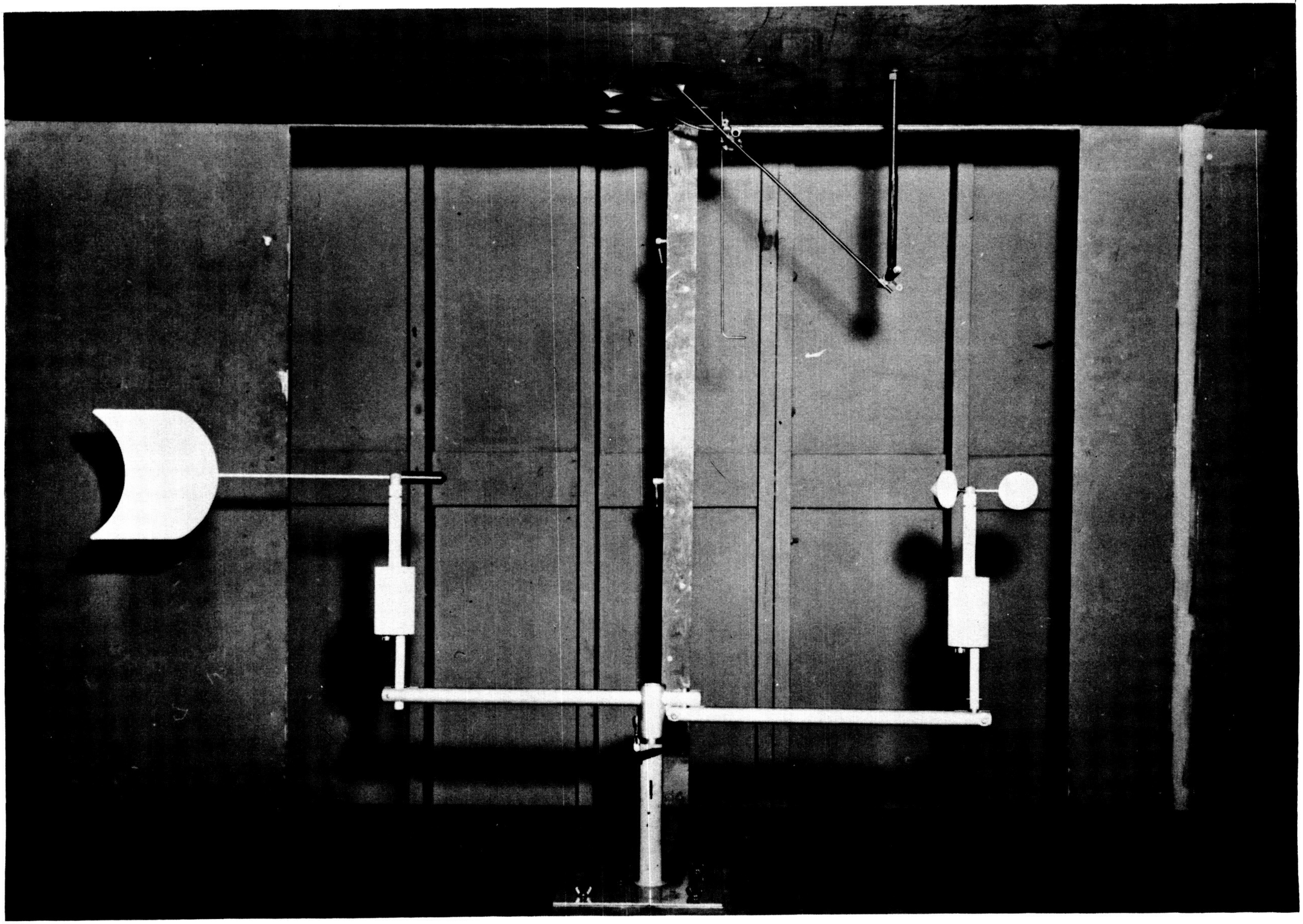


Figure 3. Climet Model C1-14 Anemometers Inside Wind Tunnel (Photo courtesy of U.S. Army, WSMR)

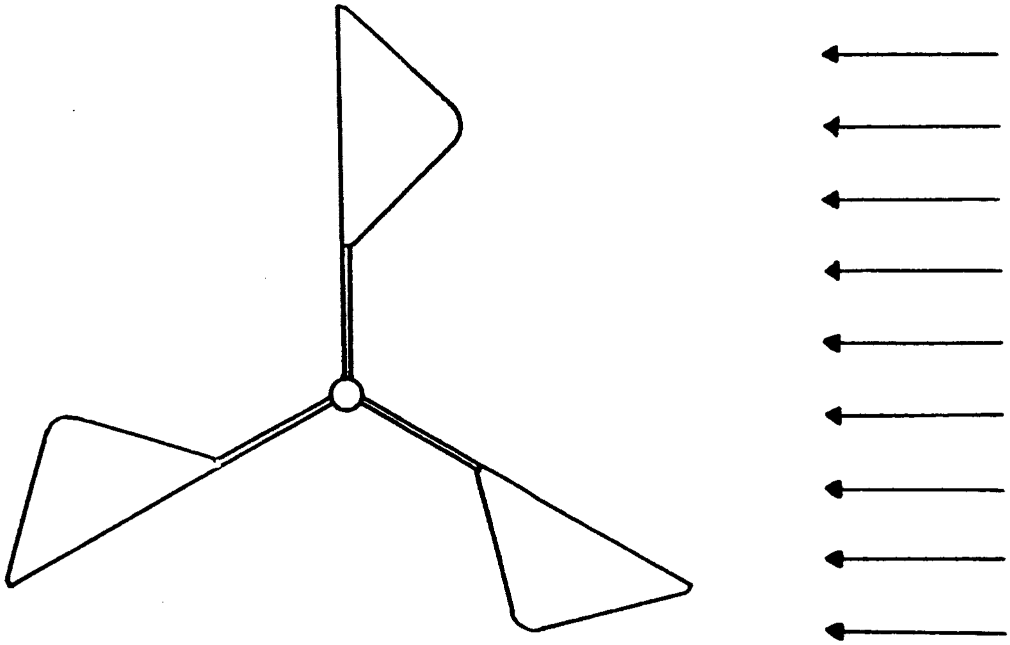


Figure 4. Cup Orientation With Reference to Wind Flow for the Top Three Cups of the Beckman & Whitley Series 50 Wind System

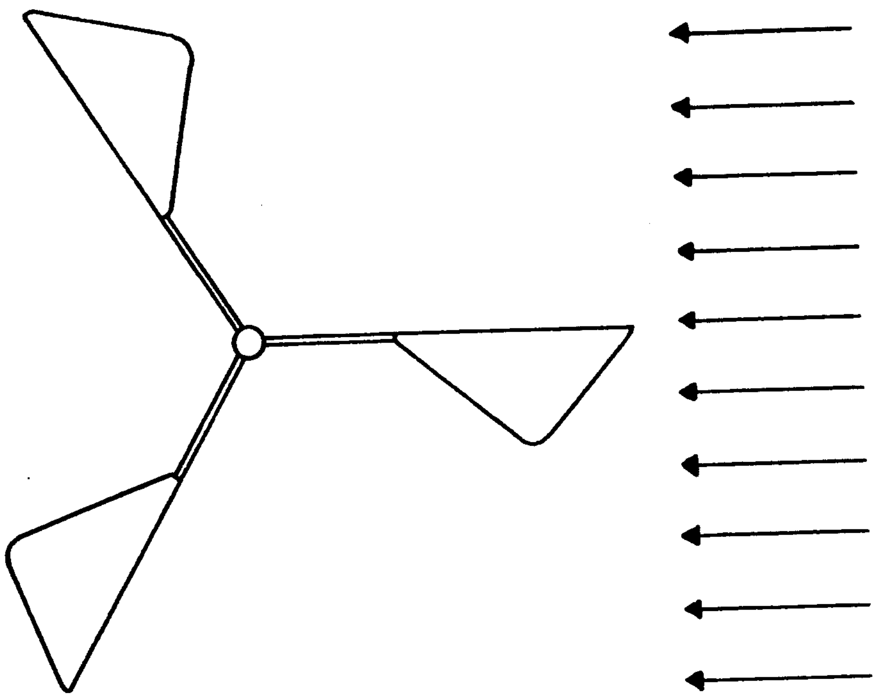


Figure 5. Cup Orientation With Reference to Wind Flow for the Climet Model C1-14 Wind System

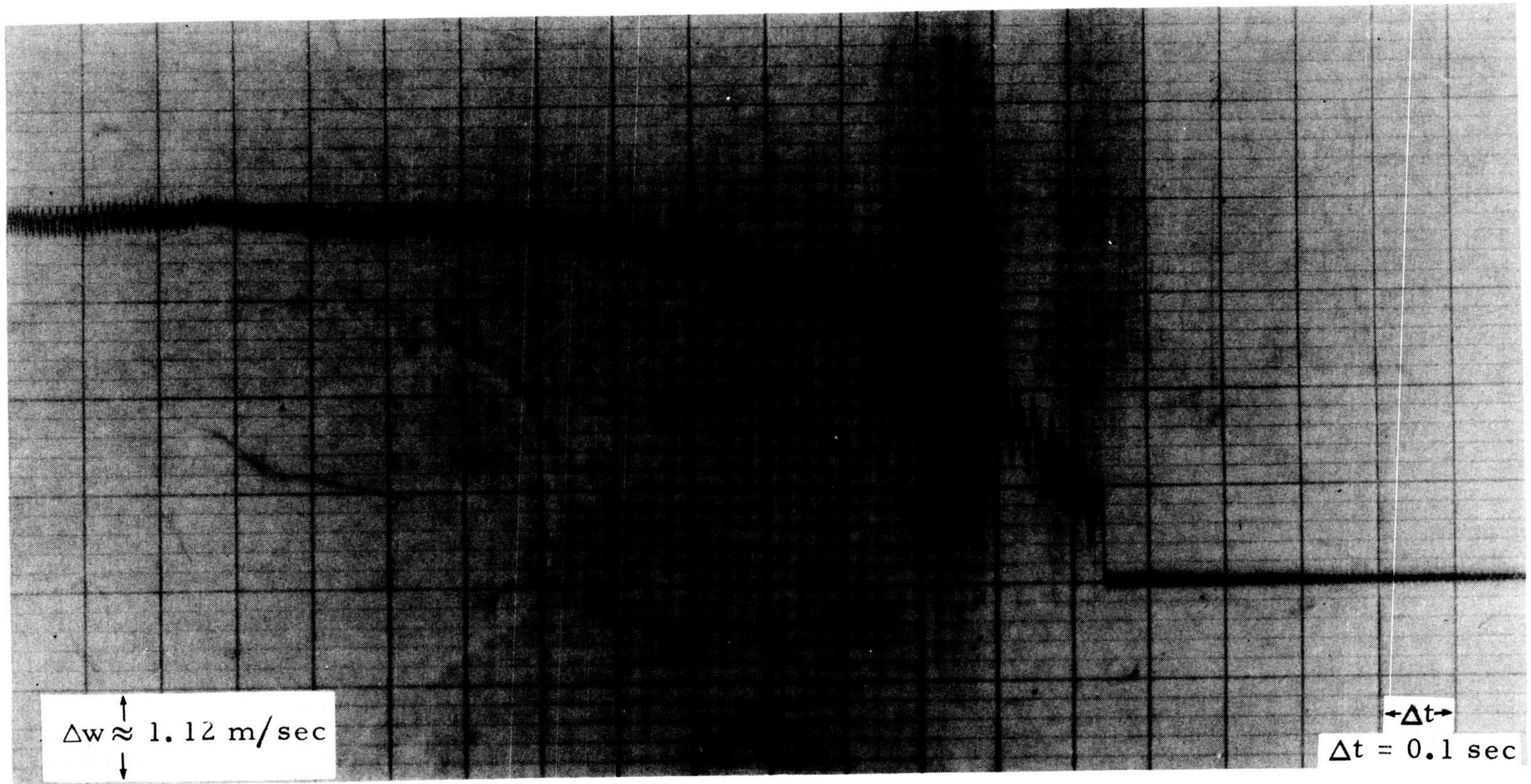


Chart Speed	0.102 m/sec	**Smallest Chart Division .....**	0.22 m/sec
Temperature	22.0° **Celsius**	**Barometric Pressure ....**	881.8 mb
Wind Speed	4.47 **m/sec**	**Distance Constant...........**	1.27 m

Figure 6. Wind Speed Chart Record for the Beckman & Whitley Series 50 Wind Speed Sensor for a Wind Speed of 4.47 m/sec

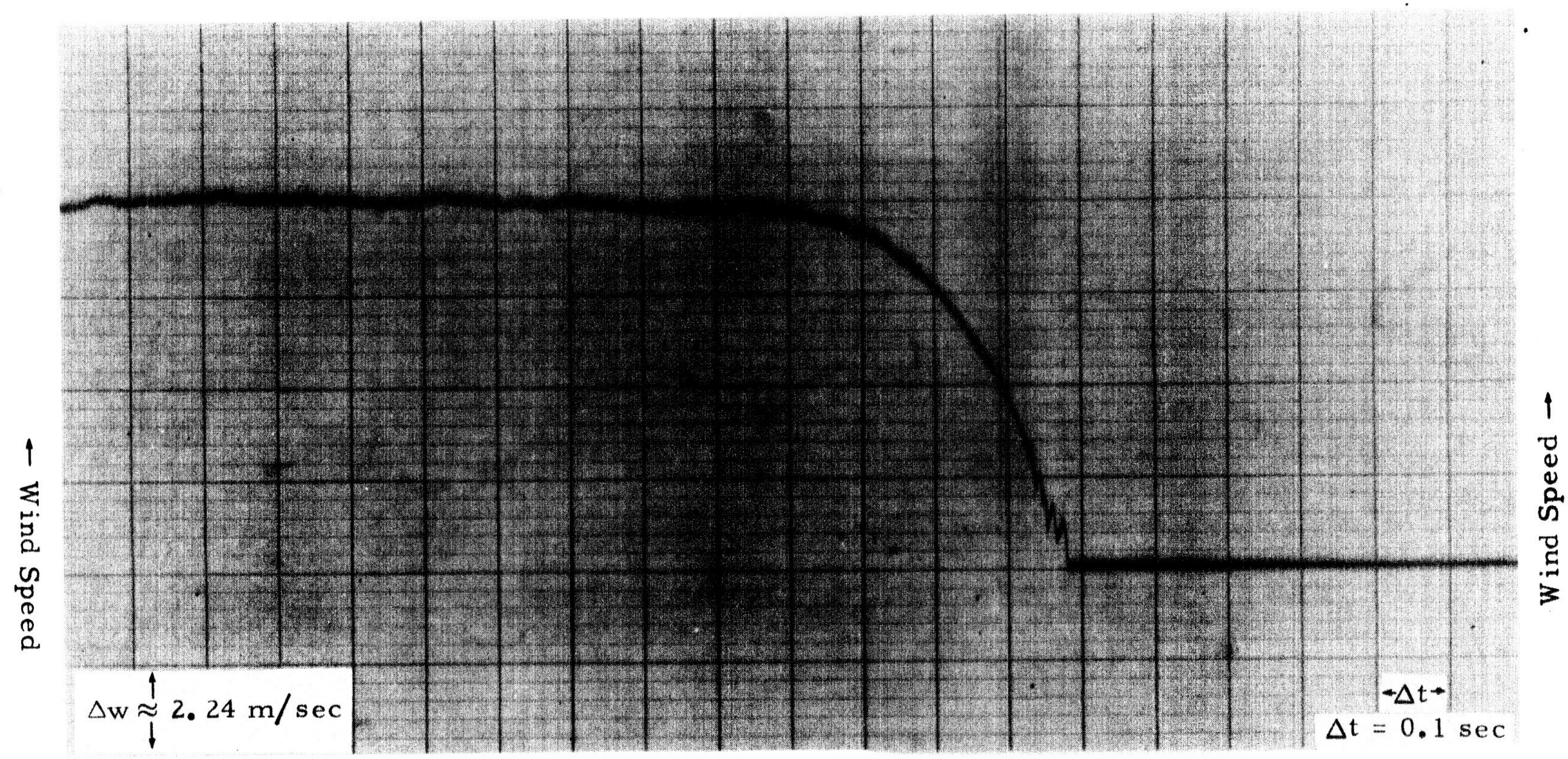


Chart Speed......	0.102 m/sec	Smallest Chart Division	0.45 m/sec
Temperature.....	22.0° Celsius	Barometric Pressure........	881.8 mb
Wind Speed.......	8.94 m/sec	Distance Constant...........	1.12 m

Figure 7. Wind Speed Chart Record for the Beckman & Whitley Series 50 Wind Speed Sensor for a Wind Speed of 8.94 m/sec

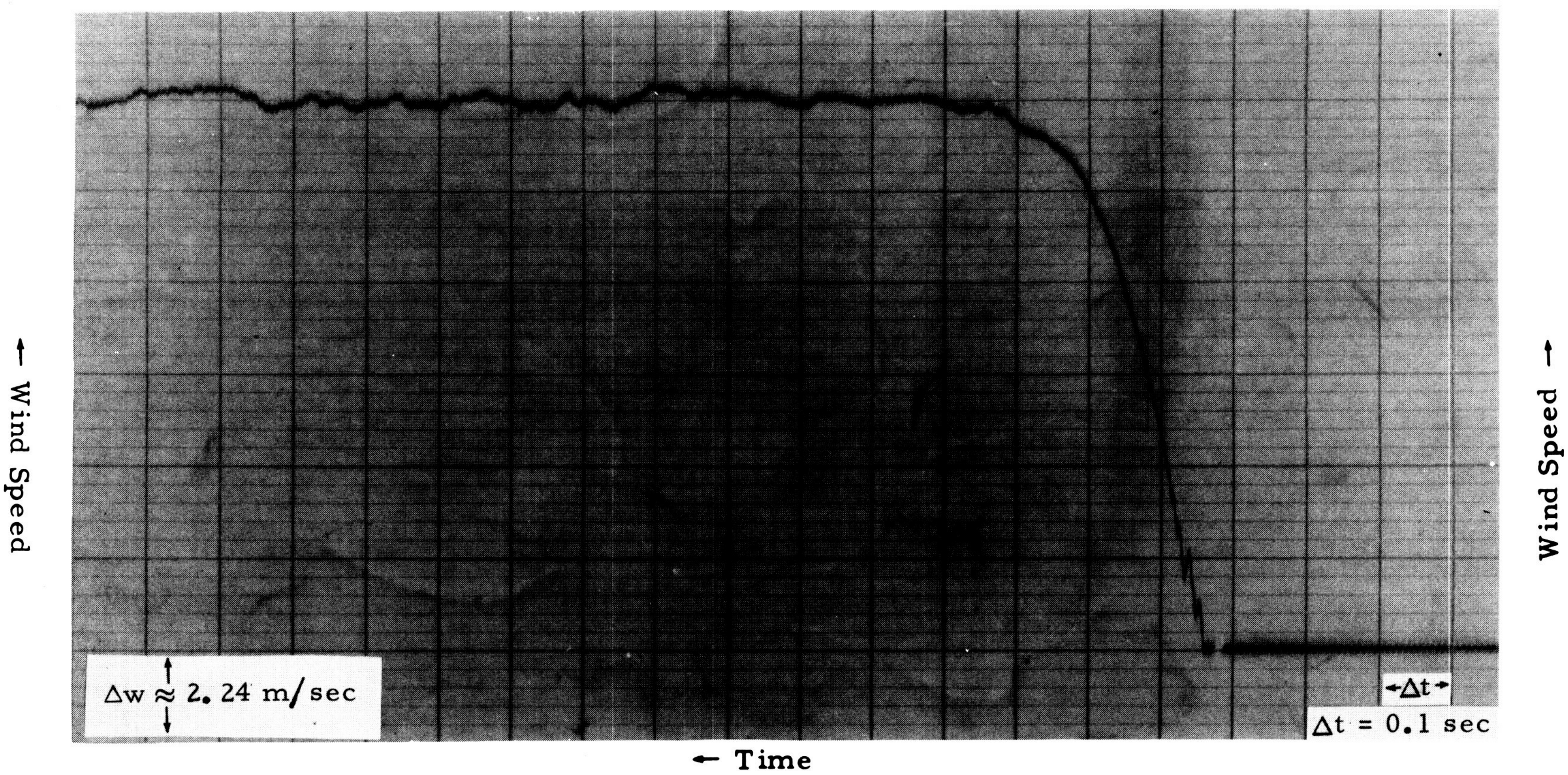


Chart Speed...... 0.102 m/sec

Temperature..... 22.0° Celsius

Wind Speed....... 13.41 m/sec

Smallest Chart Division ..... 0.45 m/sec

Barometric Pressure........ 881.8 mb

Distance Constant........... 1.05 m

Figure 8. Wind Speed Chart Record for the Beckman & Whitley Series 50 Wind Speed Sensor for a Wind Speed of 13.41 m/sec

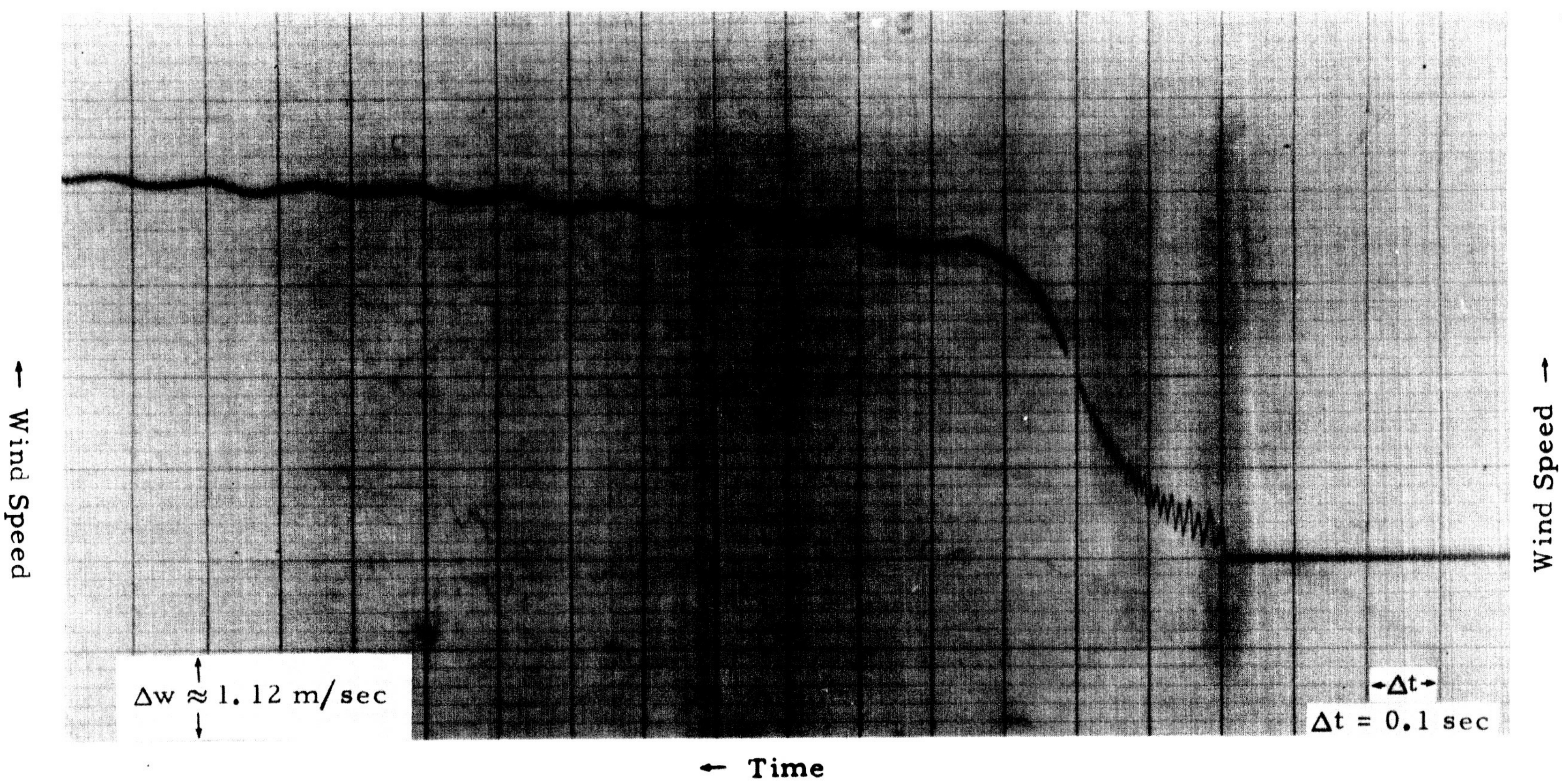


Chart Speed......	0.102 m/sec	**Smallest Chart Division .....**	**0.22 m/sec**
Temperature.....	23.0° Celsius	**Barometric Pressure........**	**880.0 mb**
Wind Speed.......	4.47 m/sec	**Distance Constant...........**	**0.79 m**

Figure 9. Wind Speed Chart Record for the Climet Model 011-1 Wind Speed Sensor for a Wind Speed of 4.47 m/sec

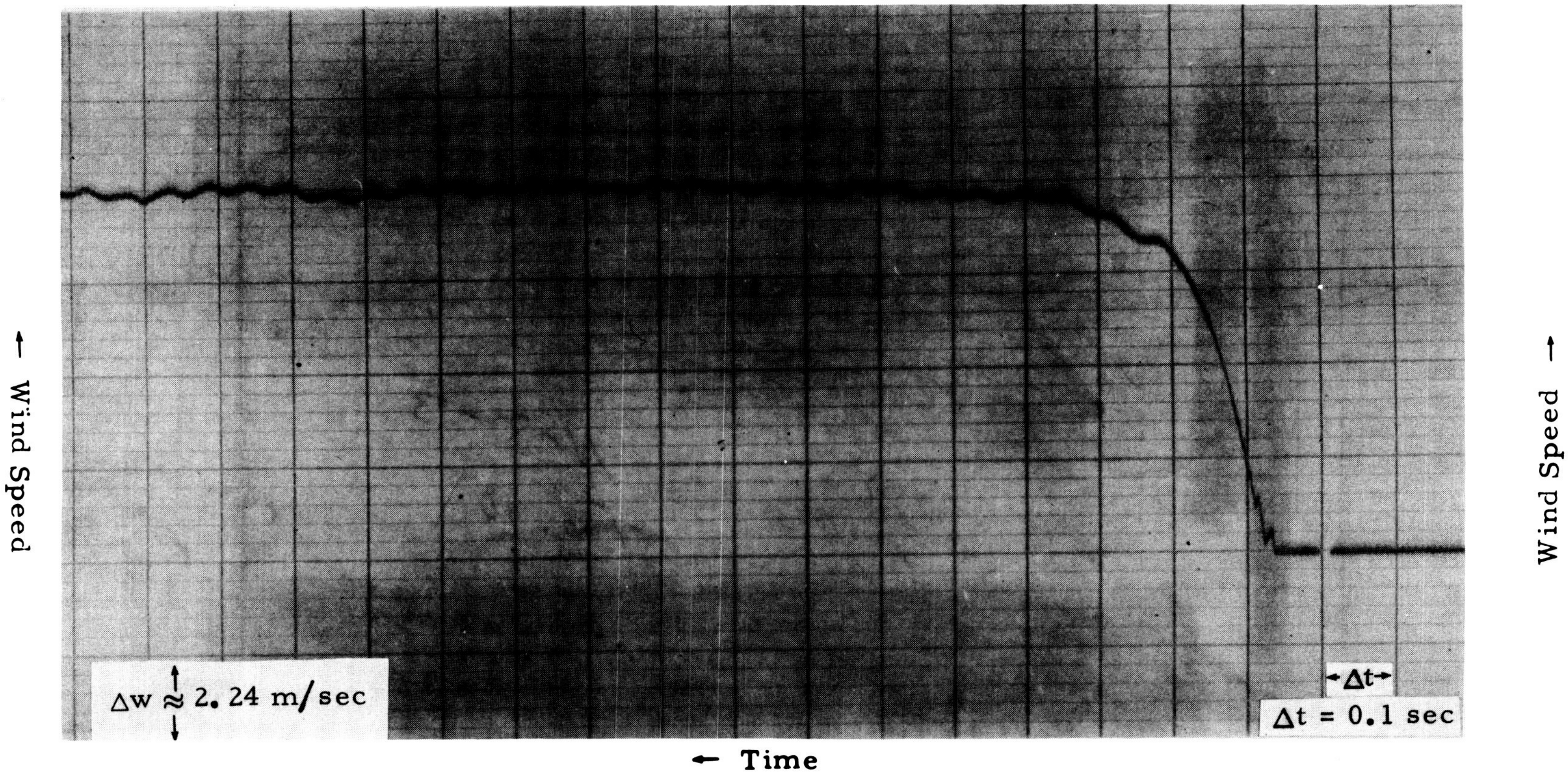


Chart Speed......	0.102 m/sec	Smallest Chart Division	0.45 m/sec
Temperature.....	23.0° Celsius	Barometric Pressure........	880.0 mb
Wind Speed.......	8.94 m/sec	Distance Constant...........	0.75 m

Figure 10. Wind Speed Chart Record for the Climet Model 011-1 Wind Speed Sensor for a Wind Speed of 8.94 m/sec

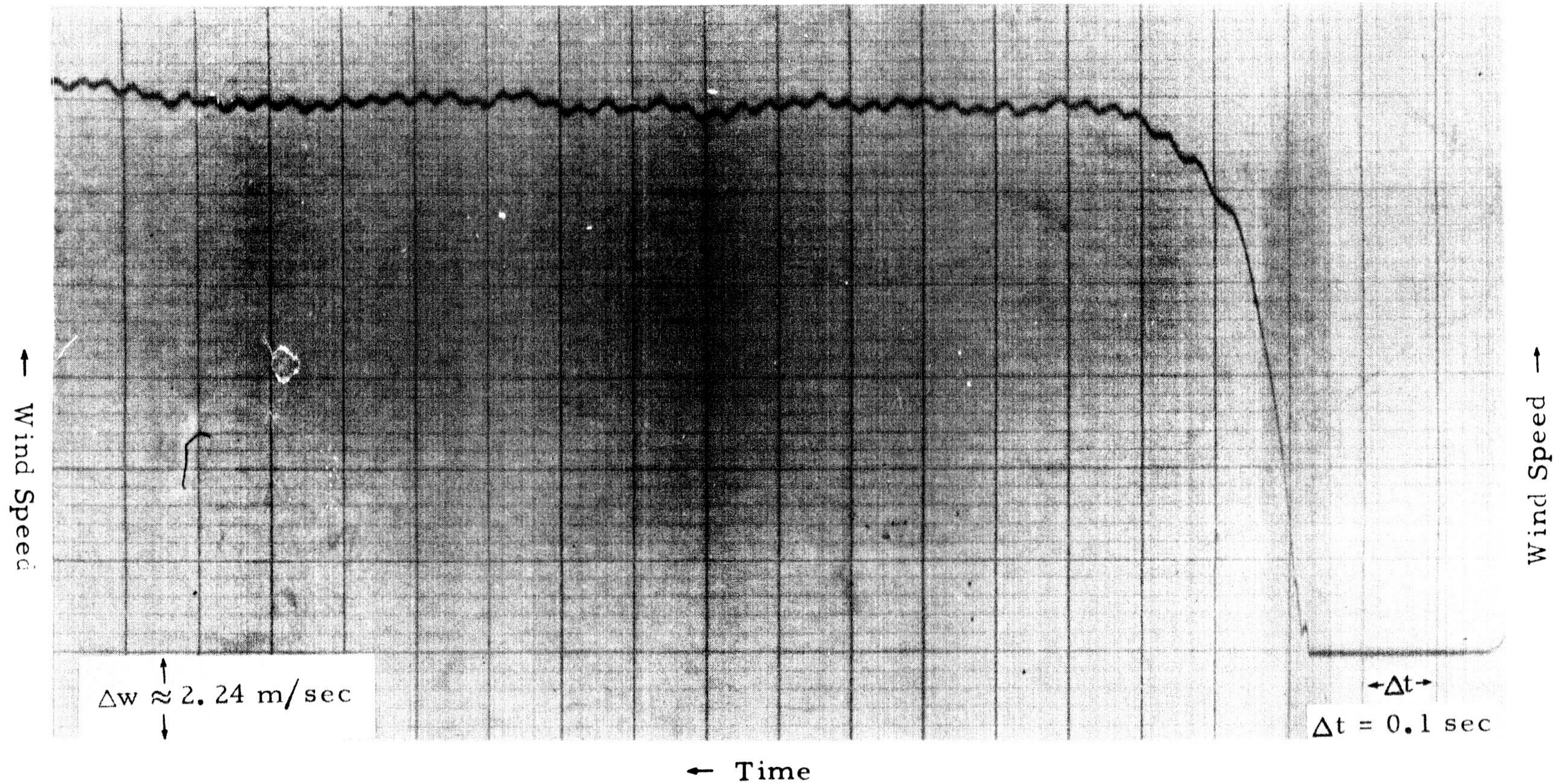


Chart Speed	0.102 m/sec	Smallest Chart Division	0.45 m/sec
Temperature	24.0° Celsius	Barometric Pressure	880.3 mb
Wind Speed.......	13.41 m/sec	Distance Constant...........	0.83 m

Figure 11. Wind Speed Chart Record for the Climet Model 011-1 Wind Speed Sensor for a Wind Speed of 13.41 m/sec

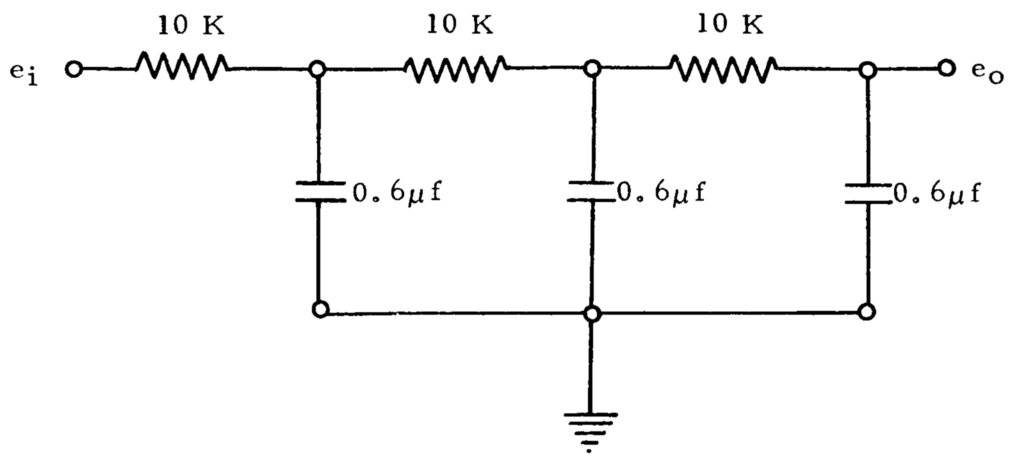


Figure 12. Schematic of Electronic Filter Used to Filter the Output Signal of the Beckman & Whitley Series 50 Wind Speed Sensor

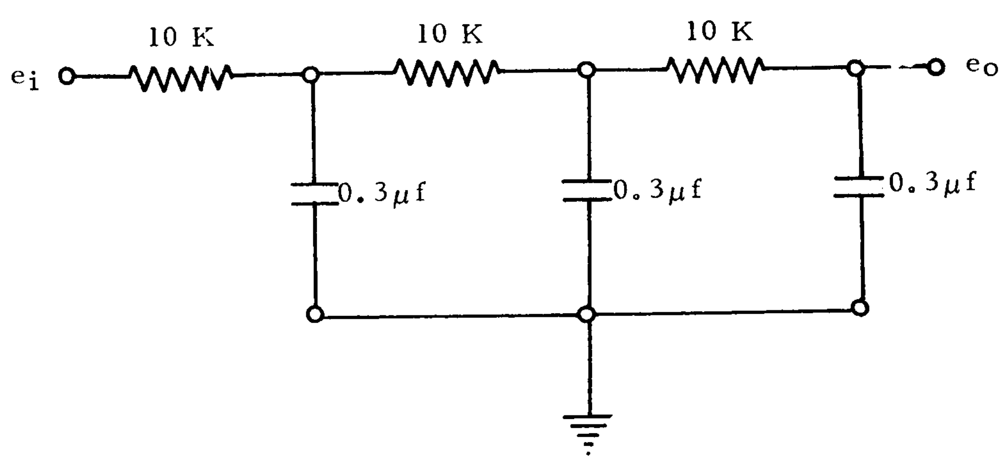


Figure 13. Schematic of Electronic Filter Used to Filter the Output Signal of the Climet Model 011-1 Wind Speed Sensor

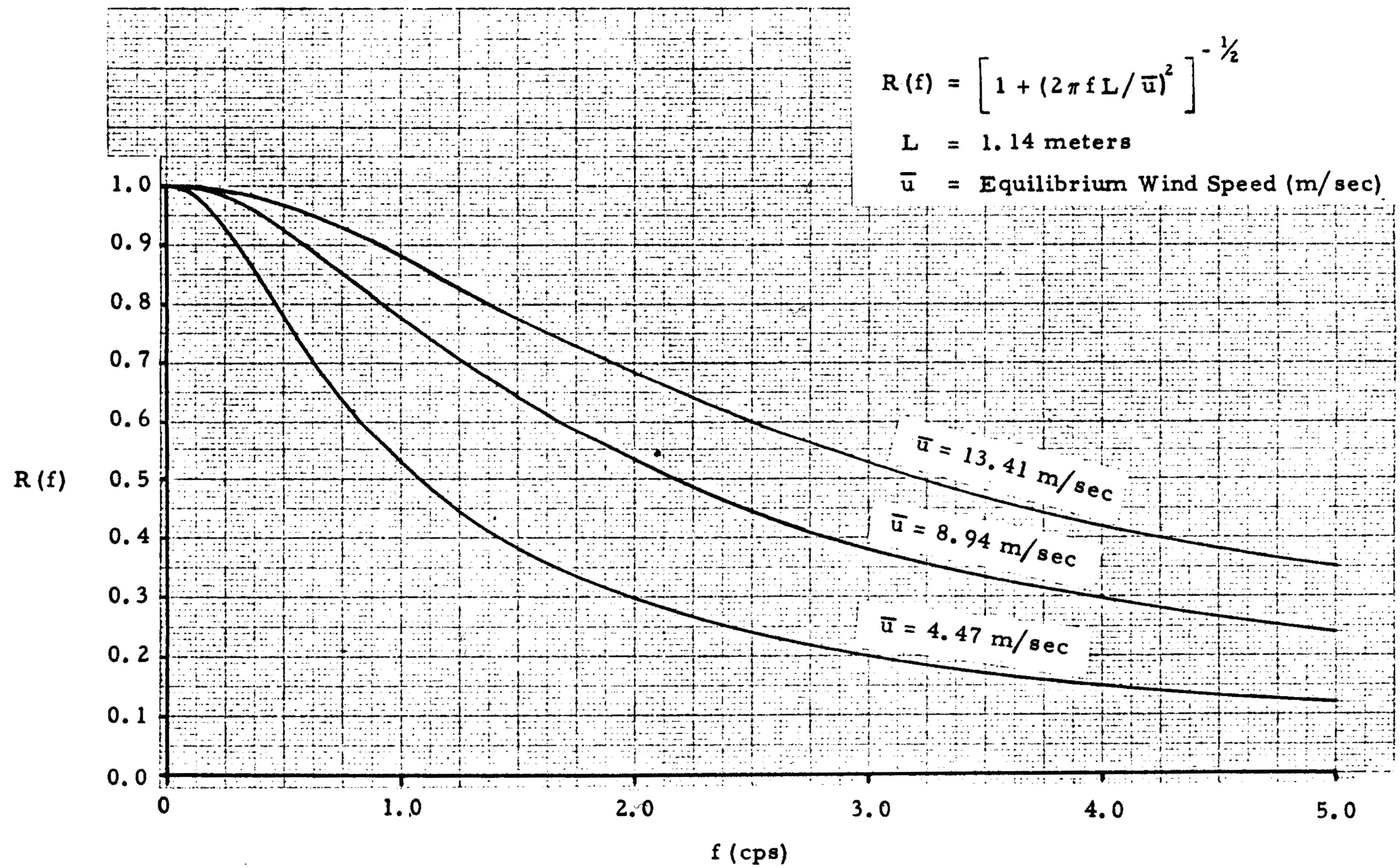


Figure 14. Frequency Response Curves for the Beckman & Whitley Series 50 Wind Speed Sensor

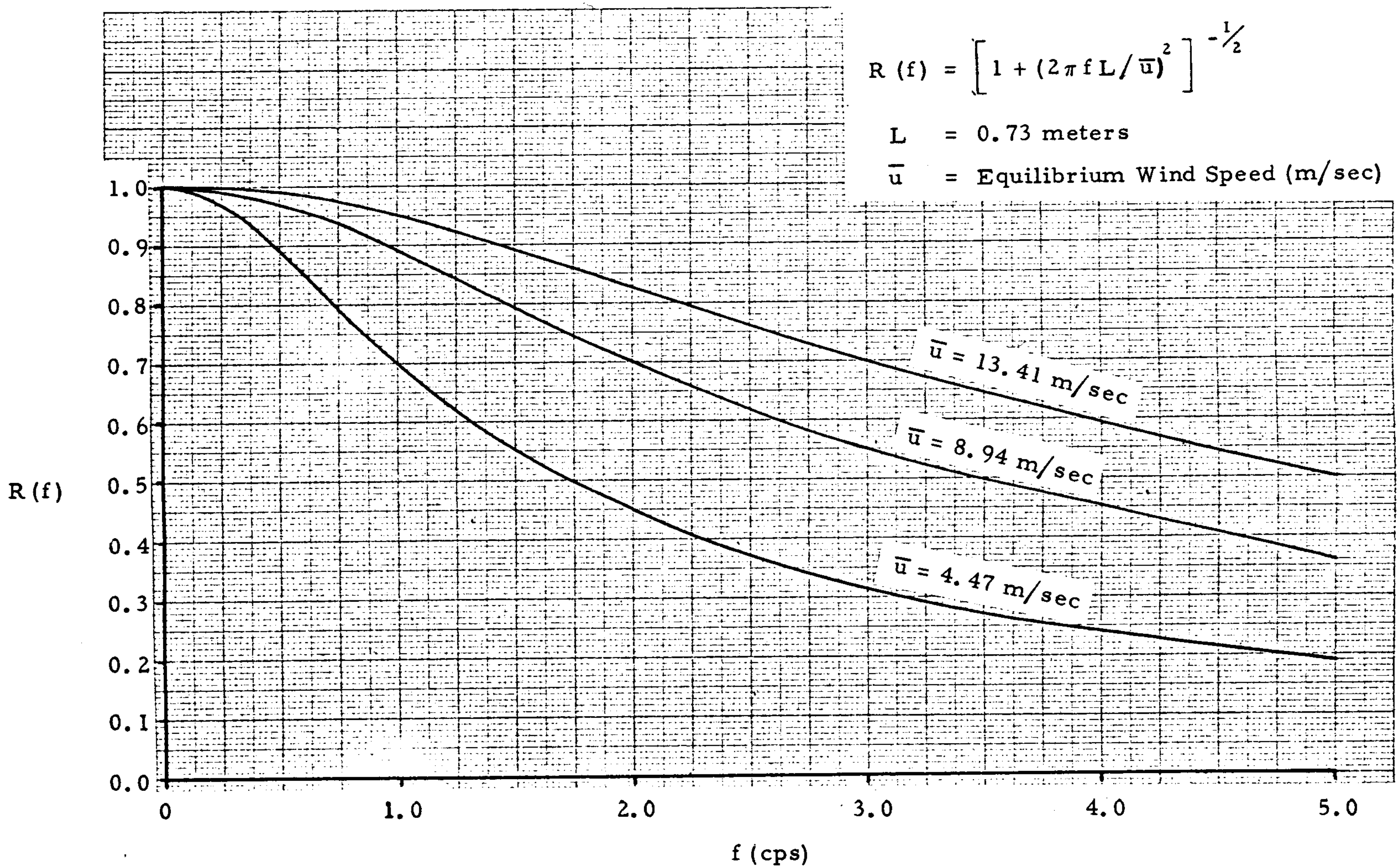


Figure 15. Frequency Response Curves for the Climet Model 011-1 Wind Speed Sensor

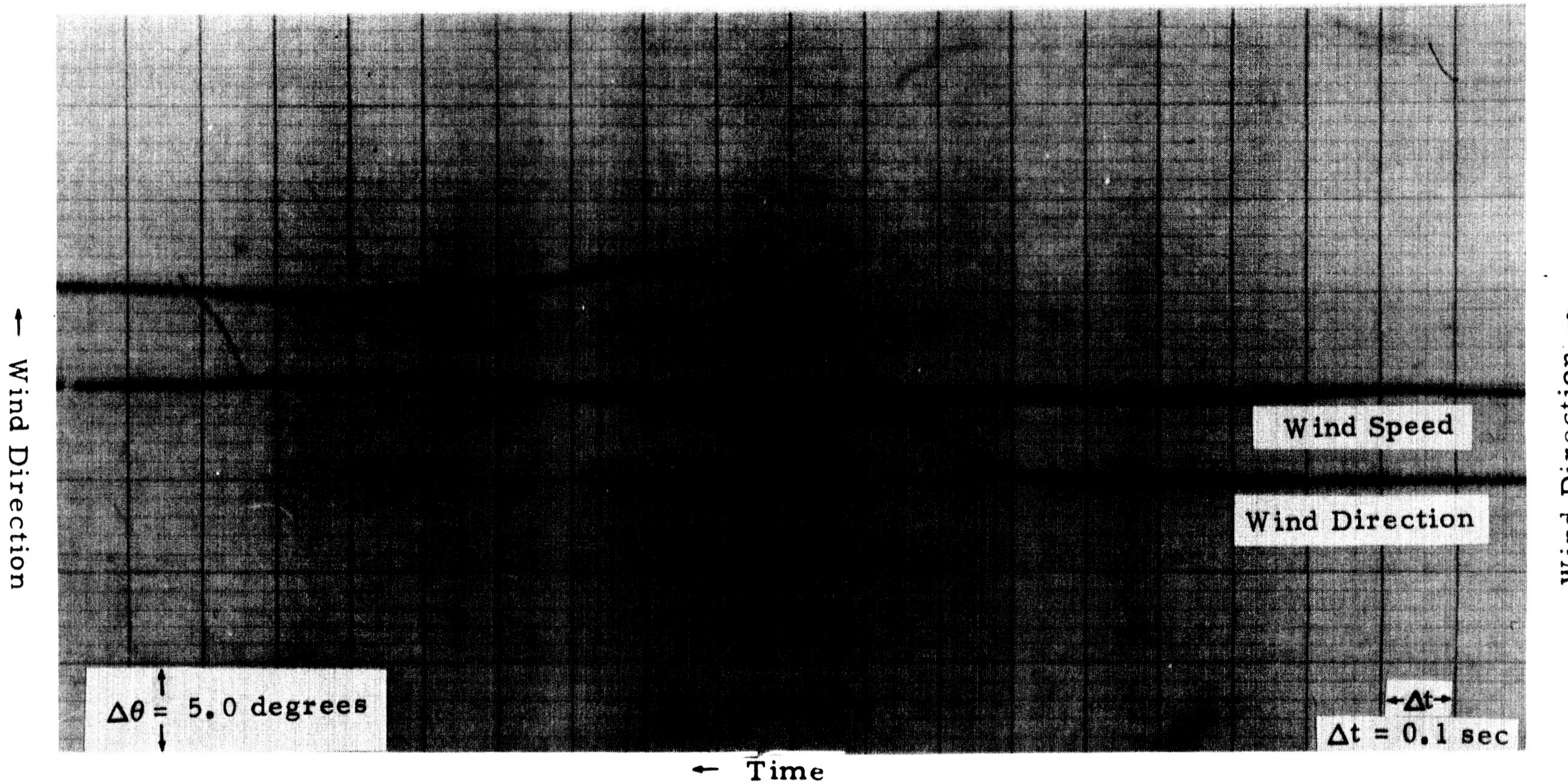


Chart Speed ...... 0.102 m/sec		Smallest Chart Division..... 1.0 degree	
Temperature ..... 25.0° Celsius		Barometric Pressure........ 878.3 mb	
Wind Speed....... 4.47 m/sec		Damping Ratio.............. 0.55	

Figure 16. Wind Direction Chart Record for the Beckman & Whitley Series 50 Wind Direction Sensor (Quick 1 Vane) for a Wind Speed of 4.47 m/sec and a Deflection Angle of 10 degrees

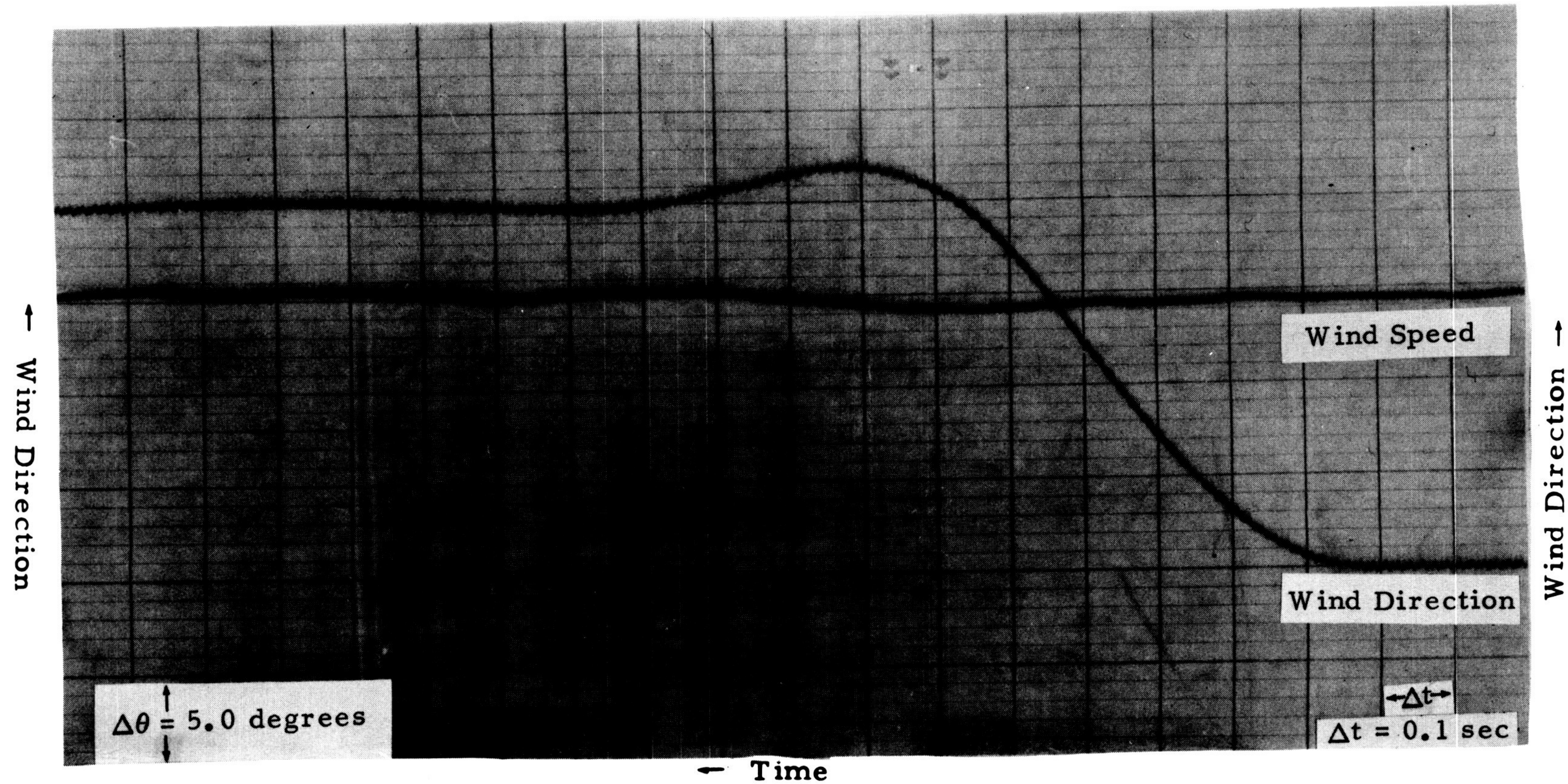


Chart Speed......	0.102 m/sec	Smallest Chart Division	1.0 degree
Temperature.....	25.0° Celsius	Barometric Pressure........	878.3 mb
Wind Speed.......	4.47 m/sec	Damping Ratio..............	0.59

Figure 17. Wind Direction Chart Record for the Beckman & Whitley Series 50 Wind Direction Sensor (Quick 1 Vane) for a Wind Speed of 4.47 m/sec and a Deflection Angle of 20 degrees

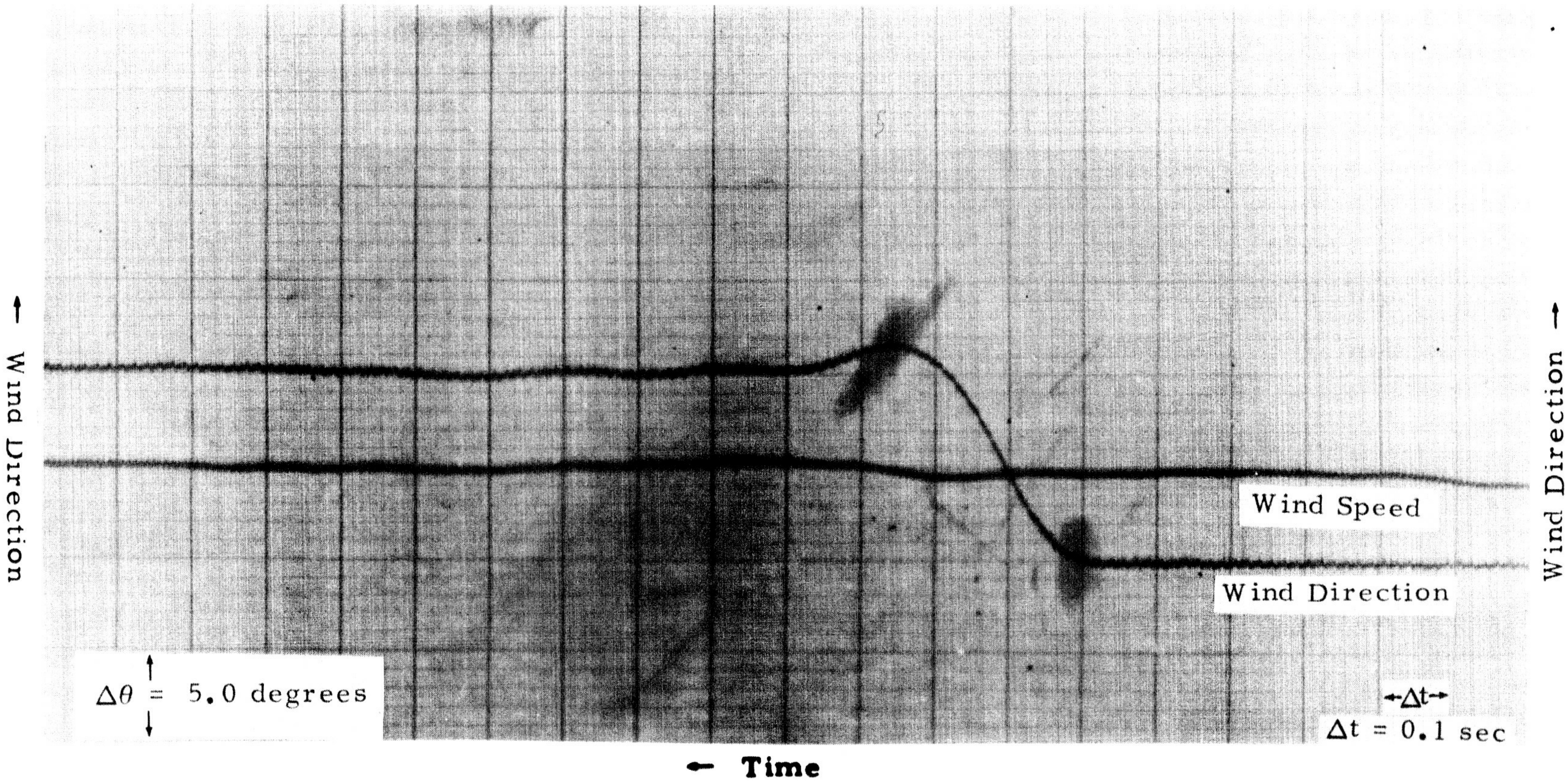


Chart Speed......	0.102 m/sec	**Smallest Chart Division**	1.0 degree
Temperature.....	25.0° Celsius	**Barometric Pressure**	878.5 mb
Wind Speed.......	8.94 m/sec	**Damping Ratio**..............	0.52

Figure 18. Wind Direction Chart Record for the Beckman & Whitley Series 50 Wind Direction Sensor (Quick 1 Vane) for a Wind Speed of 8.94 m/sec and a Deflection Angle of 10 degrees

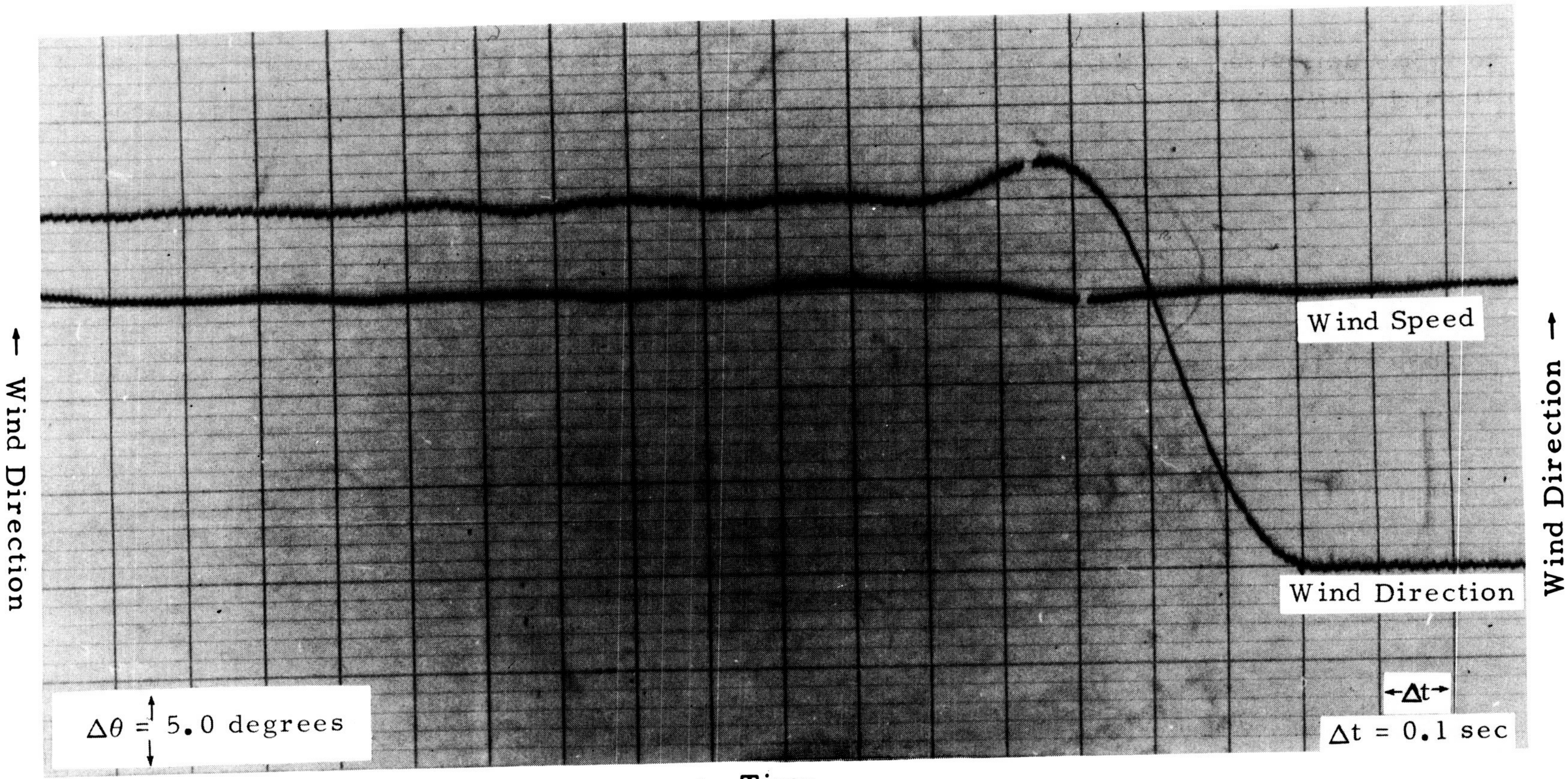


Chart Speed	0.102 m/sec	**Smallest Chart Division .....**	1.0 degree
Temperature	25.0° Celsius	**Barometric Pressure ....**	878.3 mb
Wind Speed.......	8.94 m/sec	**Damping Ratio.............**	0.59

Figure 19. Wind Direction Chart Record for the Beckman & Whitley Series 50 Wind Direction Sensor (Quick 1 Vane) for a Wind Speed of 8.94 m/sec and a Deflection Angle of 20 degrees

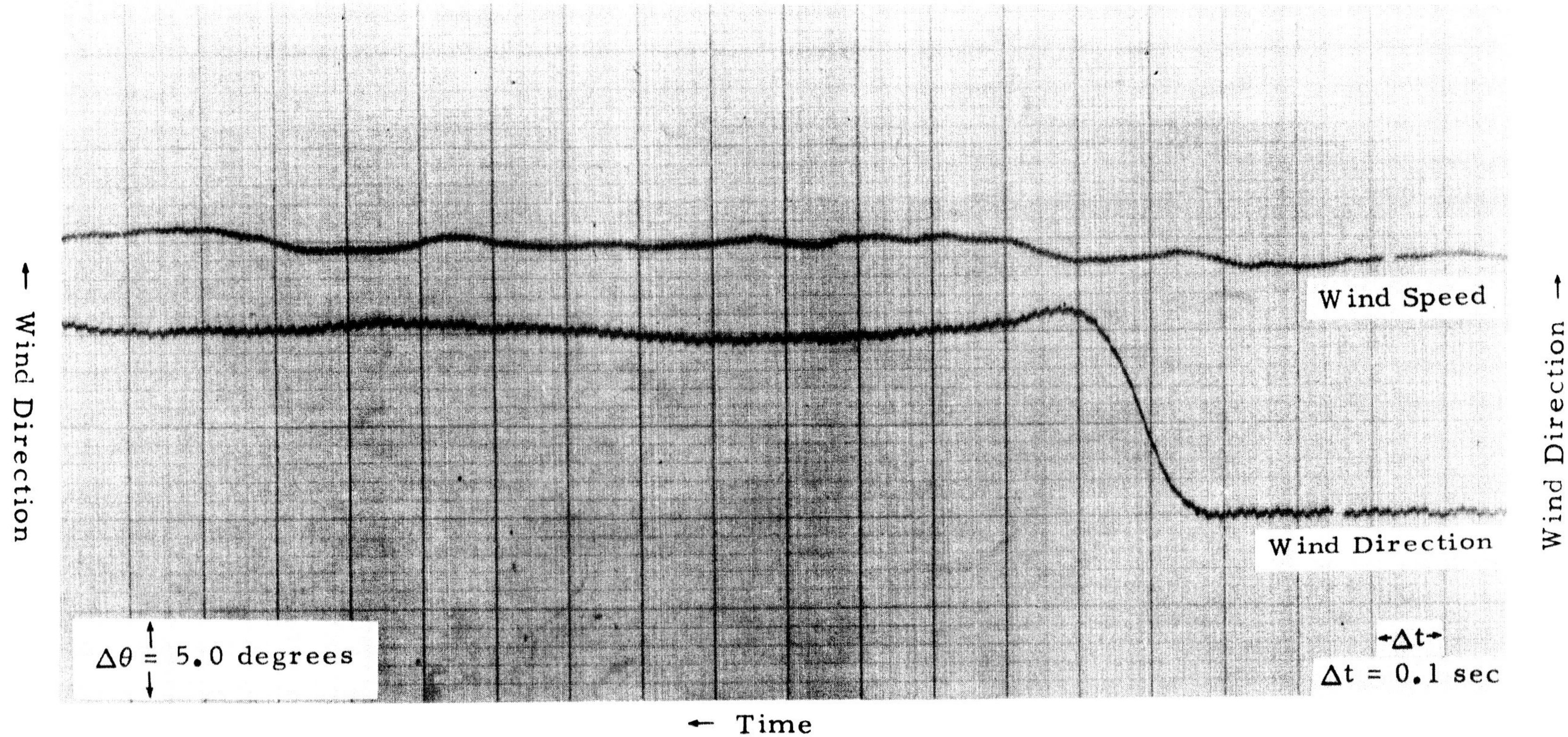


Chart Speed......	0.102 m/sec	Smallest Chart Division	1.0 degree
Temperature.....	25.5° Celsius	Barometric Pressure........	878.5 mb
Wind Speed.......	13.41 m/sec	Damping Ratio..............	0.59

Figure 20. Wind Direction Chart Record for the Beckman & Whitley Series 50 Wind Direction Sensor (Quick 1 Vane) for a Wind Speed of 13.41 m/sec and a Deflection Angle of 10 degrees

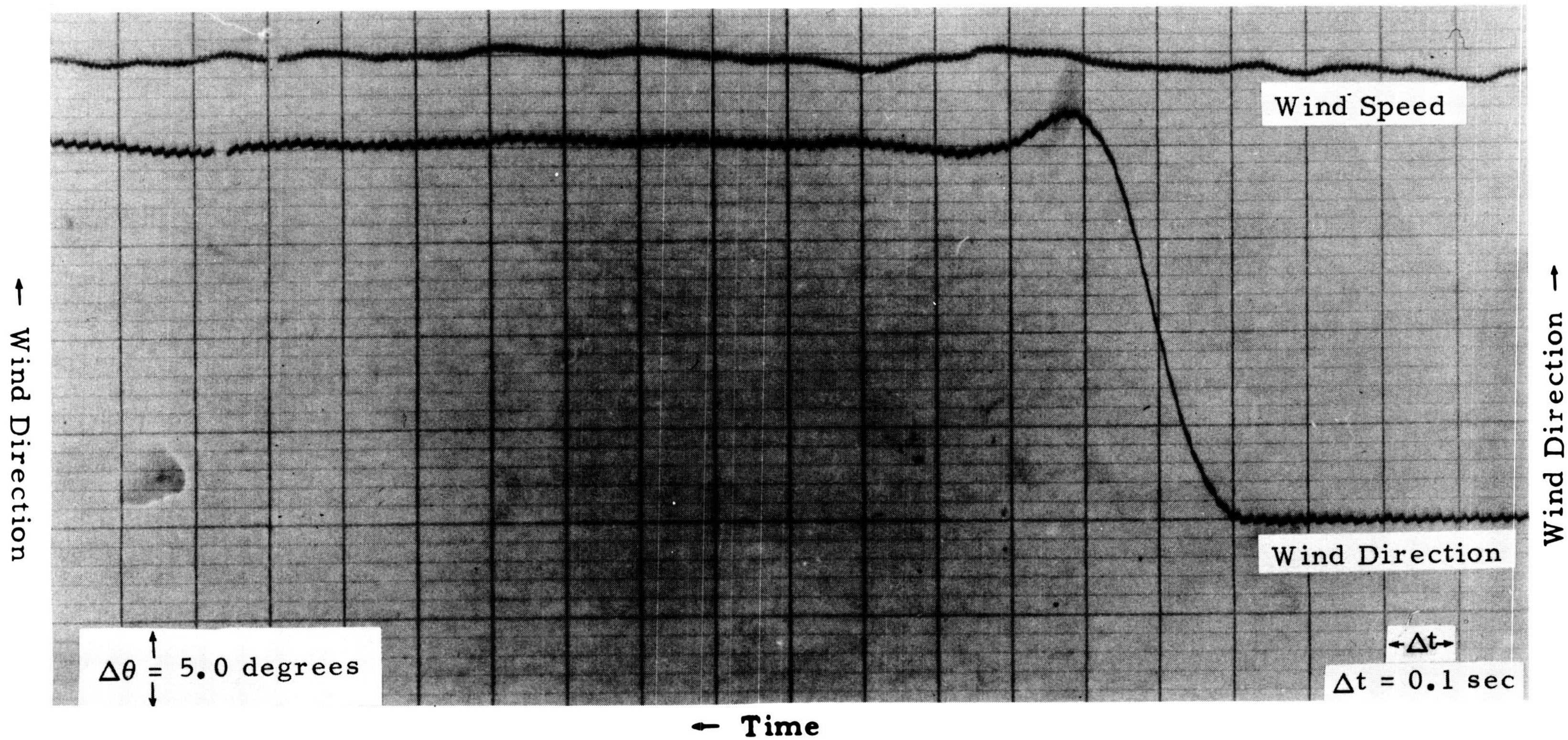
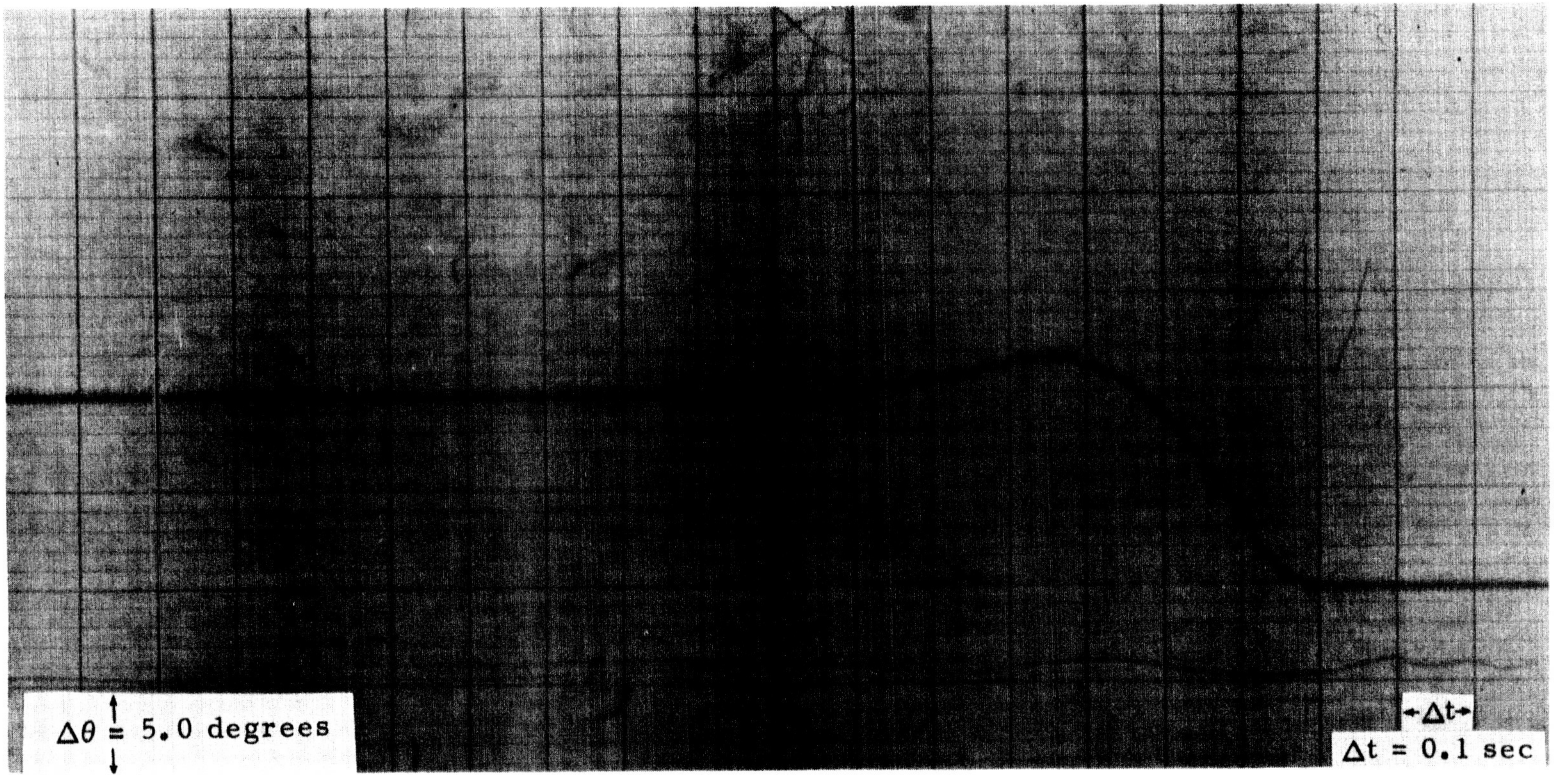


Chart Speed	0.102 m/sec	Smallest Chart Division	1.0 degree
Temperature	25.5° Celsius	Barometric Pressure........	878.5 mb
Wind Speed.......	13.41 m/sec	Damping Ratio..............	0.60

Figure 21. Wind Direction Chart Record for the Beckman & Whitley Series 50 Wind Direction Sensor (Quick 1 Vane) for a Wind Speed of 13.41 m/sec and a Deflection Angle of 20 degrees



← Time

Chart Speed	0.102 m/sec	Smallest Chart Division......	1.0 degree
Temperature	23.0° Celsius	Barometric Pressure........	886.9 mb
Wind Speed.......	4.47 m/sec	Damping Ratio..............	0.48

Figure 22. Wind Direction Chart Record for the Climet Model 012-1 Wind Direction Sensor for a Wind Speed of 4.47 m/sec and a Deflection Angle of 10 degrees

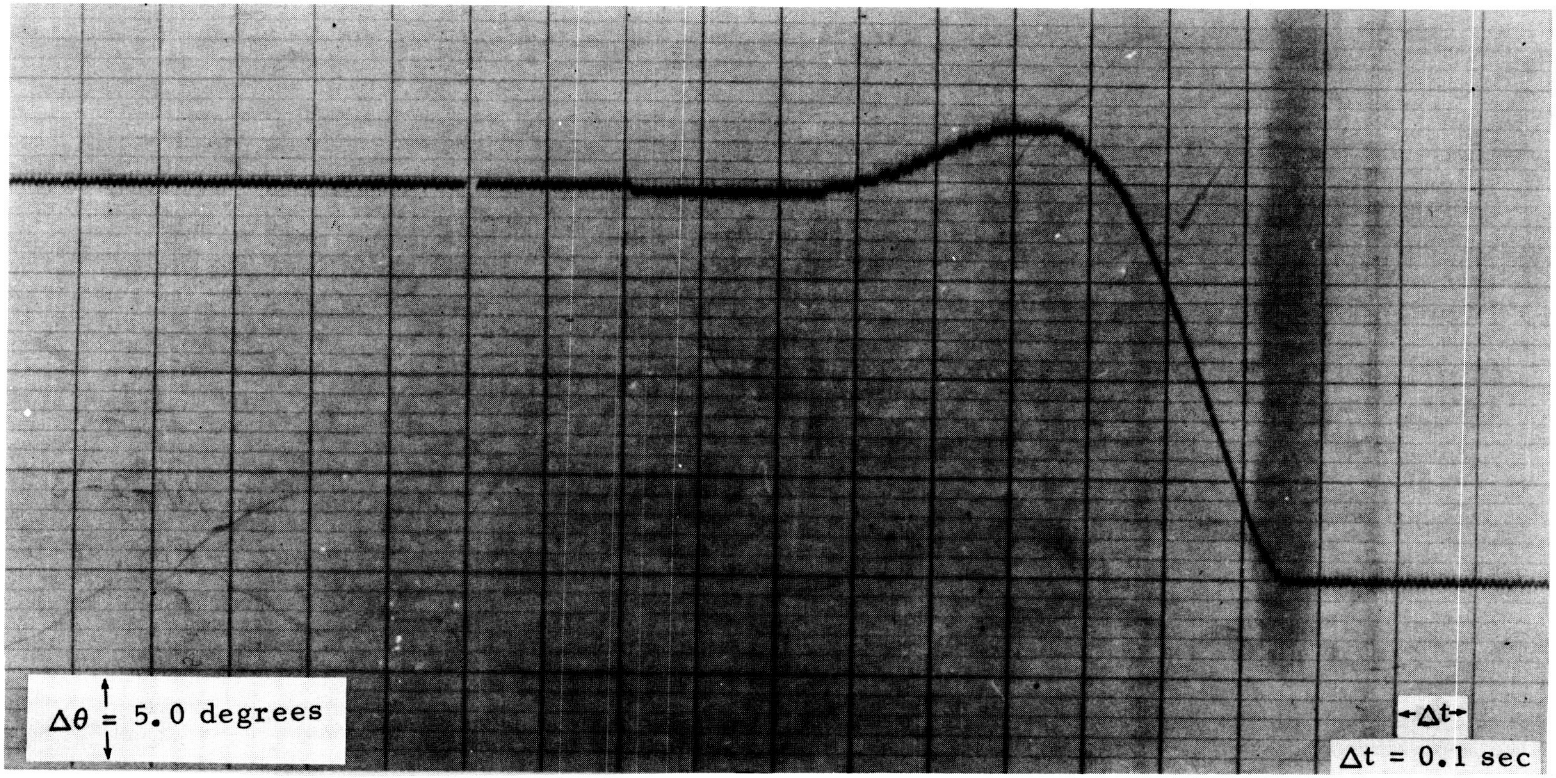


Chart Speed	0.102 **m/sec**	**Smallest Chart Division**	1.0 degree
Temperature	23.0° **Celsius**	**Barometric Pressure**	886.9 mb
Wind Speed.......	4.47 **m/sec**	**Damping Ratio**...............	0.49

Figure 23. Wind Direction Chart Record for the Climet Model 012-1 Wind Direction Sensor for a Wind Speed of 4.47 m/sec and a Deflection Angle of 20 degrees

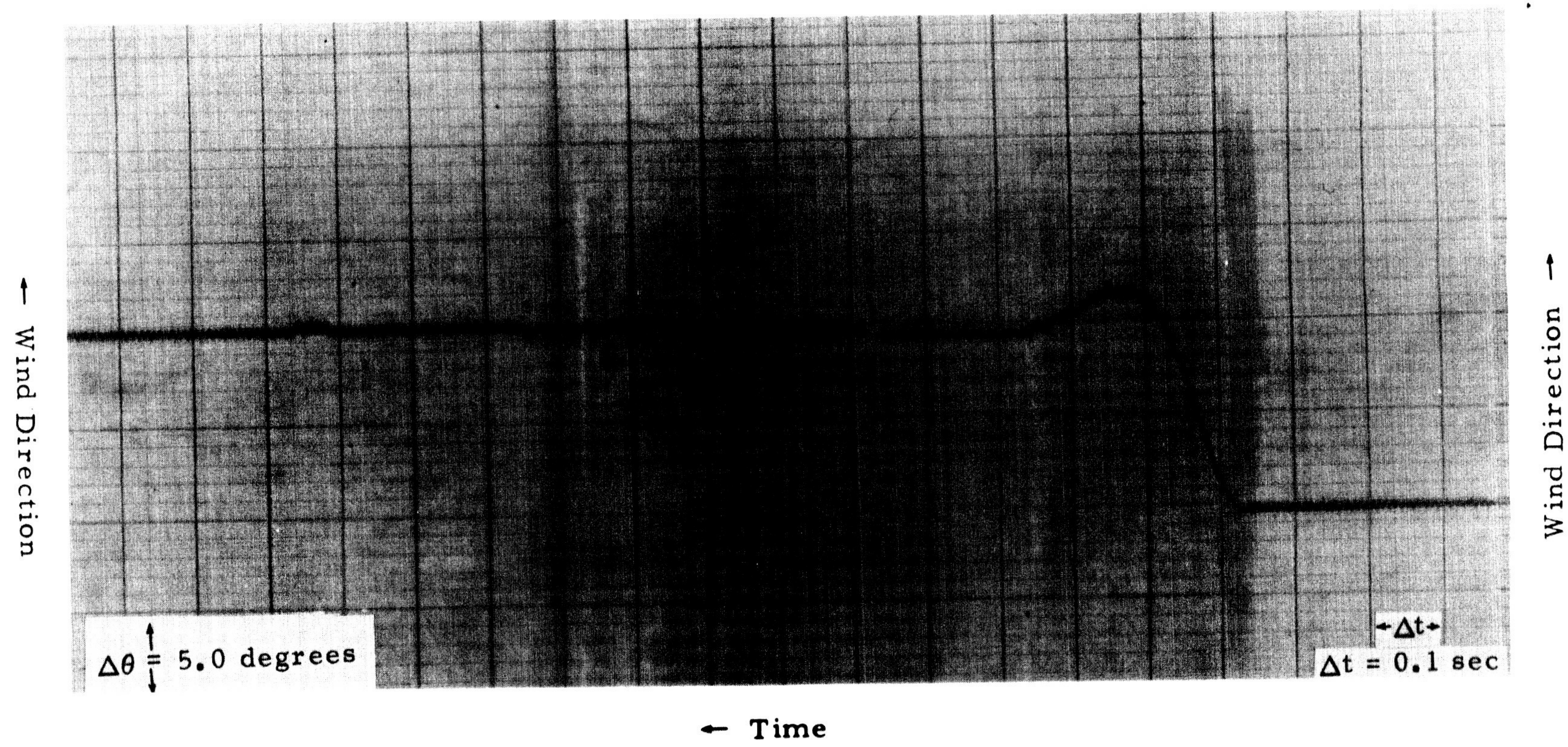


Chart Speed......	0.102 m/sec	Smallest Chart Division.......	1.0 degree
Temperature.....	23.0° Celsius	Barometric Pressure.........	887.1 mb
Wind Speed.......	8.94 m/sec	Damping Ratio...............	0.47

Figure 24. Wind Direction Chart Record for the Climet Model 012-1 Wind Direction Sensor for a Wind Speed of 8.94 m/sec and a Deflection Angle of 10 degrees

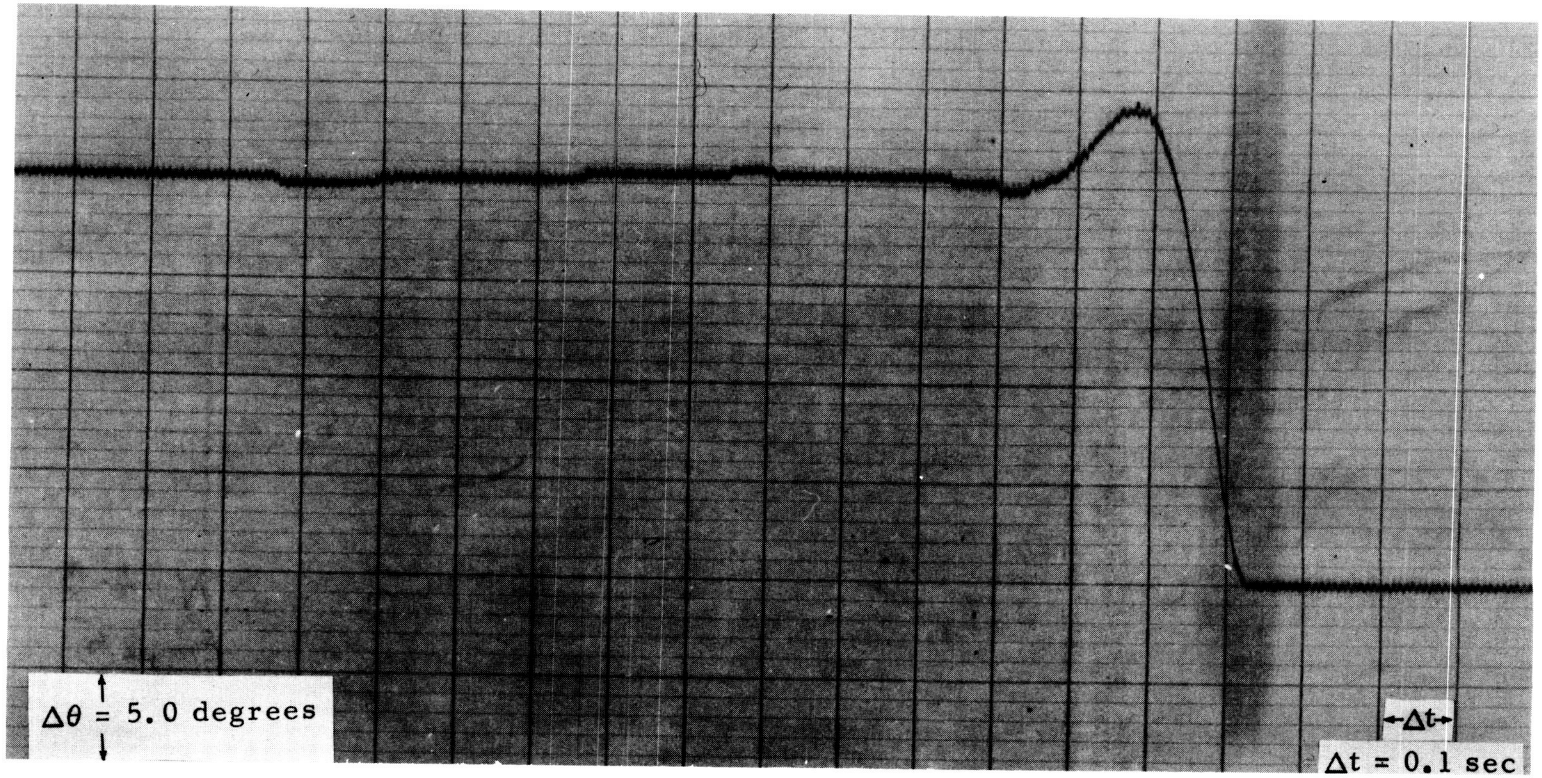


Chart Speed......	0.102 m/sec	Smallest Chart Division.....	1.0 degree
Temperature.....	23.0° Celsius	Barometric Pressure.......	887.1 mb
Wind Speed.......	8.94 m/sec	Damping Ratio..............	0.46

Figure 25. Wind Direction Chart Record for the Climet Model 012-1 Wind Direction Sensor for a Wind Speed of 8.94 m/sec and a Deflection Angle of 20 degrees

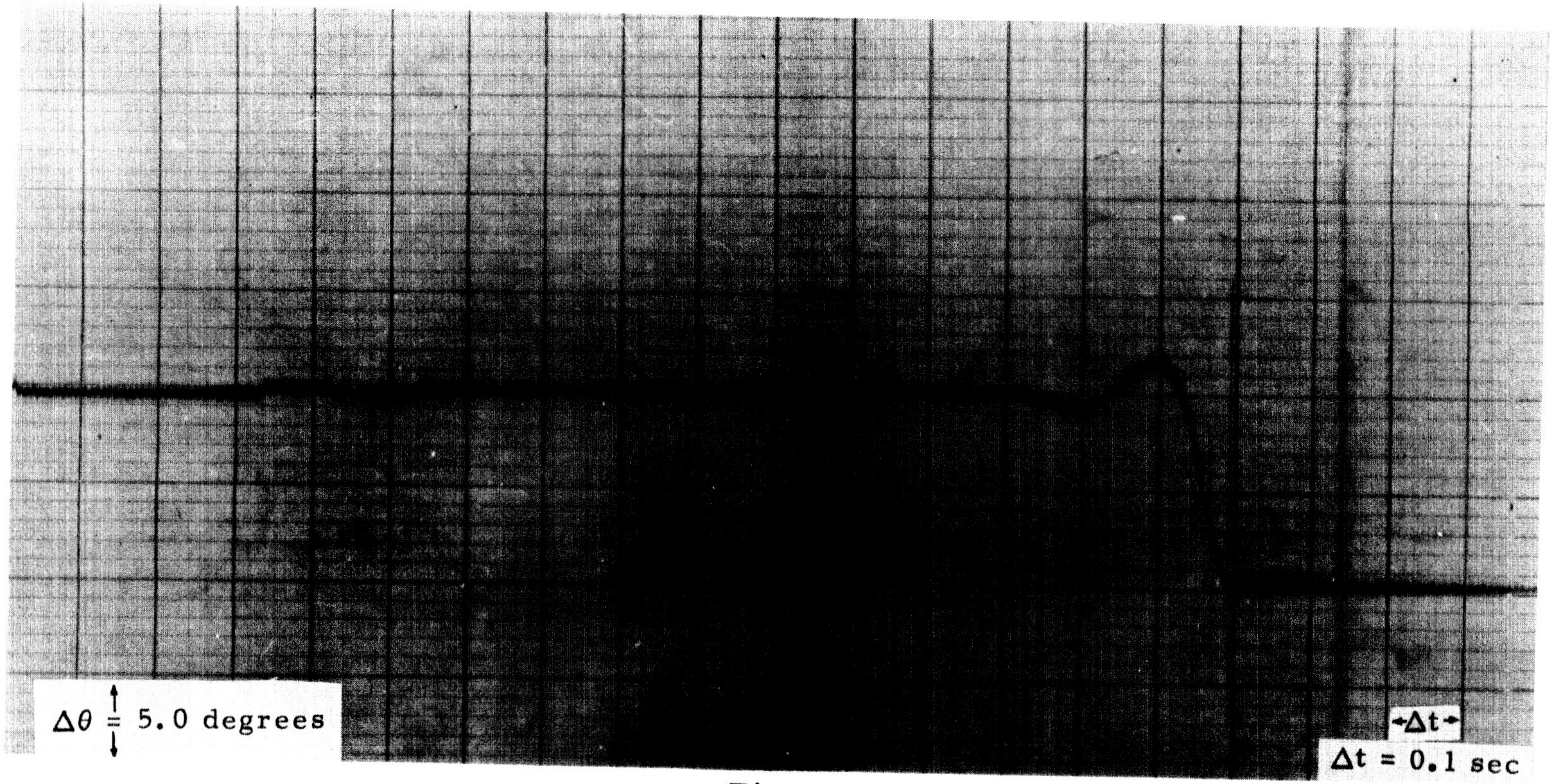


Chart Speed......	0.102 m/sec	**Smallest Chart Division .....**	1.0 degree
Temperature.....	23.0° **Celsius**	**Barometric Pressure ....**	887.1 mb
Wind Speed.......	13.41 m/sec	**Damping Ratio..............**	0.46

Figure 26. Wind Direction Chart Record for the Climet Model 012-1 Wind Direction Sensor for a Wind Speed of 13.41 m/sec and a Deflection Angle of 10 degrees

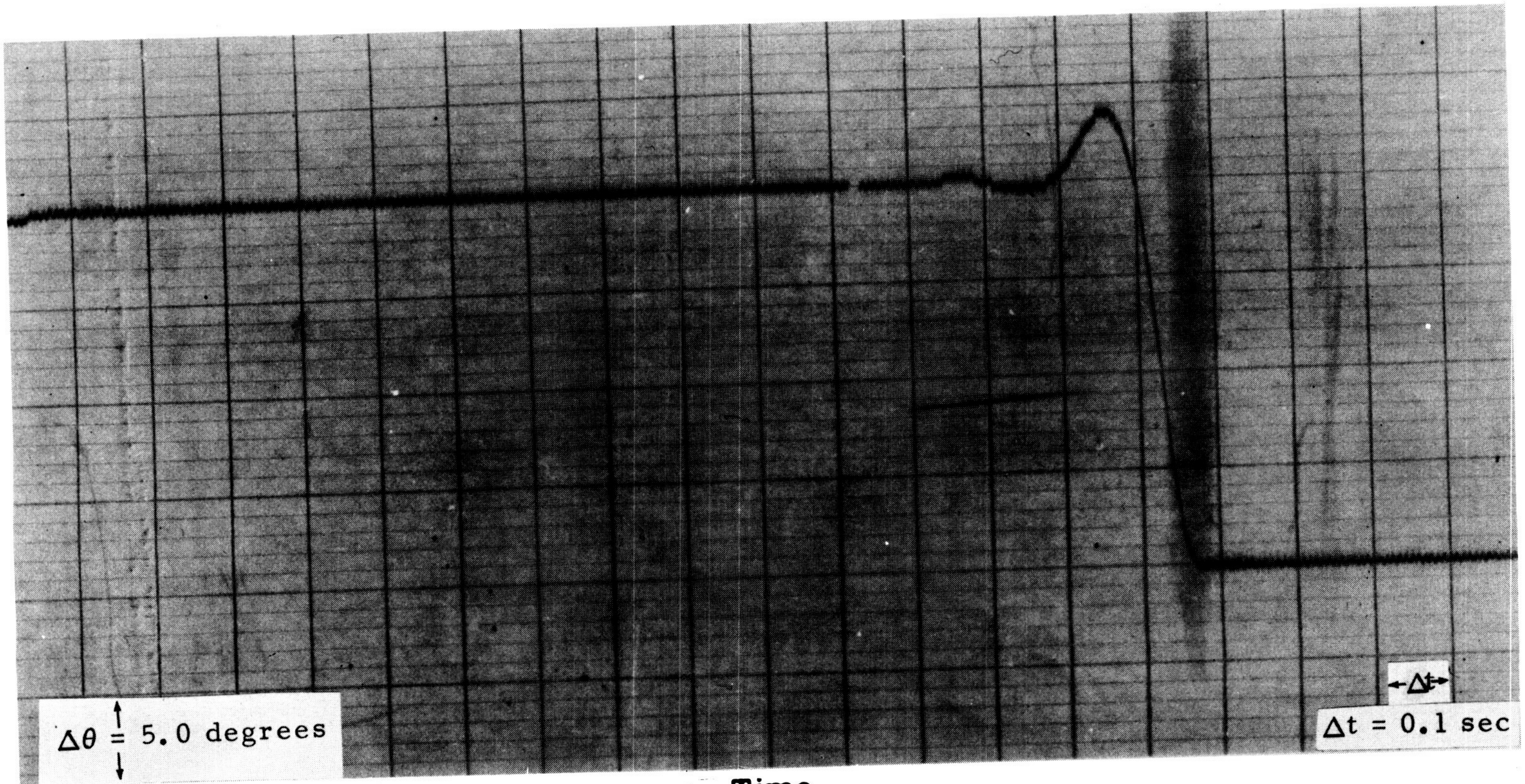


Chart Speed......	0.102 m/sec	**Smallest Chart Division .....**	1.0 degree
Temperature.....	23.0° Celsius	**Barometric Pressure ....**	887.1 mb
Wind Speed.......	13.41 m/sec	**Damping Ratio..............**	0.48

Figure 27. Wind Direction Chart Record for the Climet Model 012-1 Wind Direction Sensor for a Wind Speed of 13.41 m and a Deflection Angle of 20 degrees

TABLE I

Mean Distance Constant Values for the Beckman & Whitley Series 50 and Climet Model C1-14 Wind Speed Sensors Obtained From Wind Tunnel Testing of the Anemometers

INSTRUMENTS	TUNNEL WIND SPEED					
	4.47 (m/sec)		8.94 (m/sec)		13.41 (m/sec)	
	Distance Constant (m)	Number of Observations	Distance Constant (m)	Number of Observations	Distance Constant (m)	Number of Observations
Beckman & Whitley Series 50	1.22	42	1.12	35	1.09	38
Climet Model C1-14	0.72	31	0.72	31	0.77	38

TABLE II

Mean Damping Ratio for the Beckman & Whitley Series 50 and Climet Model C1-14 Wind Direction Sensors Obtained from Wind Tunnel Testing of the Anemometers

INSTRUMENTS	Deflection Angle	TUNNEL WIND SPEED					
		4.47 (m/sec)		8.94 (m/sec)		13.41 (m/sec)	
		Damping Ratio	No. of Obs.	Damping Ratio	No. of Obs.	Damping Ratio	No. of Obs.
Beckman & Whitley Series 50	10°	0.55	10	0.55	6	0.60	11
	20°	0.66	15	0.59	11	0.60	8
Climet Model C1-14	10°	0.48	13	0.46	15	0.45	13
	20°	0.50	12	0.48	13	0.47	14

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ANALYSIS OF WIND TUNNEL DATA FOR SEVERAL BECKMAN & WHITLEY SERIES 50 AND CLIMET MODEL C1-14 ANEMOMETERS

By Dennis W. Camp

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